DOCUMENT RESUME

ED 300 625 CE 051 290

AUTHOR	Thomas, Ruth G., Ed.; And Others
TITLE	Thinking Underlying Expertise in Specific Knowledge Domains: Implications for Vocational Education.
INSTITUTION	Minnesota Univ., St. Paul. Minnesota Research and Development Center for Vocational Education.
SPONS AGENCY	Minnesota State Board of Vocational-Technical Education, St. Paul.; Minnesota State Dept. of Education, St. Paul.
PUB DATE	Nov 88
NOTE	122p.
PUB TYPE	Reports - Research/Technical (143)
EDRS PRICE	MF01/PC05 Plus Postage.
DESCRIPTORS	*Child Rearing; *Cognitive Processes; Equipment Maintenance; *Learning Theories; Machine Repairers; Parenting Skills; Postsecondary Education; *Repair; Secondary Education; *Skill Development; Technical Occupations; *Vocational Education
IDENTIFIERS	*Expertise; Troubleshooting

ABSTRACT

This monograph contains reports of research conducted under the Higher Order Thinking Program of Research at the Minnesota Research and Development Center. A report entitled "Studying Expertise in Specific Knowledge Domains" (Ruth G. Thomas) briefly reviews previous findings regarding the general nature of expertise and discusses the objectives of the Minnesota research program. Scott D. Johnson's paper "Knowledge and Skill Differences between Expert and Novice Service Technicians on Technical Troubleshooting Tasks" is one of two papers in the monograph that focus on understanding the mental processes and structures underlying expertise in specific knowledge domains associated with vocational education. The second such paper, written by Betty D. Cooke, is entitled "Mental Processes and Knowledge Underlying Expertise in Parenting." The fourth paper, a project summary that was also written by Ruth G. Thomas, is entitled "Conclusions and Insights Regarding Expertise in Specific Knowledge Domains and Implication for Research and Educational Practice." References, tables, and figures are provided throughout the text. (MN)

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Thinking Underlying Expertise in Specific Knowledge Domains: Implications For Vocational Education

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Including Chapters by

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November 1988

Minnesota Research and Development Center for Vocational Education
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Funding for this project was provided by the State Board of Vocational Technical Education, the Minnesota Department of Education, and the Department of Vocational and Technical Education, University of Minnesota.

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ACKNOWLEDGMENTS

Research efforts are seldom the result of researchers' efforts alone. The research reported in this monograph is no exception.

The commitment on the part of the Minnesota State Board for Vocational Education and the Minnesota Department of Education to increasing understanding of higher order thinking processes in relation to work performance and the teaching of these processes in vocational education programs is exemplary and forward looking. The funds provided by the State Board for the projects reported here, for previous work which led to these projects and for current work on higher order thinking assessment and instruction that builds on these studies are gratefully acknowledged.

Thanks are also due to the Minnesota Research and Development Center (MRDC) staff for their support during various phases of the project. In particular, thanks are due to Dr. David Pucel, Director of the MRDC, for his support and facilitation of the project and to Nora Gille, Principal Secretary, Bonnie Henderson, and Kimberly Pippel for their efficient handling of meeting arrangements, budget work and manuscript typing. The support of the University of Minnesota in providing the time to conduct the research is gratefully acknowledged.

Finally, thanks are due to the non-University groups who provided access to the individuals who were involved in the study (Onan Corporation and parent educators in metropolitan area parent education programs). The contribution made by the individuals who participated in the research is also gratefully acknowledged.

ABSTRACT

This monograph contains reports of research conducted under the Higher Order Thinking Program of Research at the Minnesota Research and Development Center, Department of Vocational Education, University of Minnesota. Two studies focused on understanding the mental processes and structures underlying expertise in specific knowledge domains associated with vocational education are reported in Chapters 2 and 3. A brief review of previous findings regarding the general nature of expertise is provided in Chapter 1. Chapter 4 draws overall conclusions suggested by the findings of the two studies and presents implications and recommendations for research and educational practice.

A study of technical trouble shooting and a study of parent-child interaction were undertaken to understand the mental structures and processes underlying expertise in specific knowledge domains relevant to vocational education. A secondary purpose in choosing these two knowledge domains was to gain insight regarding differences in the nature of problems and the implications of those differences for problem solving resources and processes. Experts and novices in the two knowledge domains were presented with a problem situation. They were asked to talk aloud while they worked through the problem. Their verbal expression was audio taped. In addition, in the parent-child interaction study the subjects and their infants were video taped.

Protocols of each subject were developed by transcribing the tapes and analyzing the verbal content. Quantitative and qualitative analyses of the protocols were performed.

Results confirmed more general findings regarding expertise and provide more specific information about the mental structures and processes of experts in the knowledge domains of technical trouble shooting and child guidance. Results are summarized and analyzed with respect to what they suggest for instructional design and curricular content selection decisions.

The studies represent exemplars of a wide range of such studies that could be conducted to better understand the nature of expertise relevant to vocational education and to provide a more precise and strategic basis for instructional design and curriculum decisions.

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CHAPTER 1

STUDYING EXPERTISE IN SPECIFIC KNOWLEDGE DOMAINS

Ruth G. Thomas[1]

Higher Order Thinking Research Program

The research reported in this monograph was conducted as part of the Higher Order Thinking Research Program at the Minnesota Research and Development Center for Vocational Education Research located at the University of Minnesota. The purposes of the Higher Order Thinking Research Program are to conduct research on:

1. The nature of problems requiring higher order thinking that are of concern in vocational education

2. The nature of mental processes and structures that underlie expertise in specific knowledge domains related to work roles and contexts

3. Instructional design for developing, facilitating and improving mental processes and structures associated with specific knowledge domain expertise

4. Assessment of mental processes and structures underlying expertise in specific knowledge domains related to work roles and contexts

It is intended that this research will result in a better understanding of the nature of problems and expertise in areas relevant to vocational education and better ways of developing and assessing that expertise. The focus of the research in the Higher Order Thinking Program is on mental processes and structures underlying expertise in specific knowledge domains. A specific knowledge domain is an area of knowledge that goes beyond general knowledge that the general population would be expected to possess. A specific knowledge domain is what one needs to know in order to successfully practice in a particular

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[1]Dr. Ruth Thomas is Director of the Higher Order Thinking Research Program at the Minnesota Research and Development Center for Vocational Education Research and Associate Professor of Home Economics Education at the University of Minnesota, St. Paul, MN.

profession, trade or role. A specific knowledge domain is acquired by education, training or experience in a setting which exposes the individual to the concepts, principles and processes associated with the phenomena on which the domain focuses (e.g., diseases, equipment, children, crops, accounts, etc.). Much of the research on higher order thinking has been more generically focused with the intent to understand the general processes involved in human thought. The research reported in this monograph is focused on thinking underlying specific types of expertise that require command of a specific domain of knowledge.

Mental processes include the processing of information as it is influenced by perception and individual dispositions. Mental structures include the forms, organization, arrangements and systems in which knowledge exists in the human mind. Expertise refers to the possession of a high level of skill or proficiency in solving a problem, resolving a situation or performing some function. As it is used here, it also refers to the production of particularly creative, interesting or insightful thought, the noting of especially subtle nuances, the depth and breadth of comprehension and interpretation, and the quality of conclusions, evaluations and judgments. A more complete discussion of terms and concepts central to this research program can be reviewed in Thomas and Litowitz, 1986.

The Higher Order Thinking Research Program has been funded for a three year period by the Minnesota State Board for Vocational Education. In the first year of the program, an agenda for inquiry to investigate higher order thinking in relation to vocational education was produced (Thomas, R. & Litowitz, L., 1986). This inquiry agenda called for research on the nature of problems, the nature of problem solvers, and the improvement of thinking processes and their prerequisites through education. The two studies reported in Chapters 2 and 3 of the present monograph were completed during the higher order thinking research program's second year. These two studies respond to the portion of the inquiry agenda calling for studies that contribute to understanding of the nature of problem solvers. The two studies focus on answering the question, "What knowledge and mental processes guide, organize and form effective actions in working with specific knowledge domain problems?" These studies examine relationships between knowledge and mental processes and the ability to solve problems.

Overview of the Specific Knowledge Domain Expert-Novice Studies Reported in This Monograph

The two studies focus on the nature of expertise in two knowledge domains within vocational education: technical trouble shooting and parenting. Technical trouble shooting and parenting seem intuitively to be very different kinds of problems. They

were selected for this reason. The inquiry agenda referred to above calls for research on the nature of problems of concern in vocational education. Two different problem areas were selected for the research reported in this monograph to provide the opportunity to gain understanding of differences in the nature of problems and to compare and contrast very different types of expertise.

A primary motivation for initiating the two studies was the assumption that better understanding of the differences between novices and experts in relation to a specific domain of knowledge would be helpful in more precisely, strategically, and consciously designing instruction within a knowledge domain that would help novices move toward expertise. The two studies might be viewed as examples of a host of studies that could be conducted in all vocational education fields to provide a knowledge base for instructional design.

The studies reported here examine expertise in terms of knowledge acquisition processes, and problem identification, representation, and solution processes. Stored knowledge is described in terms of content, amount, arrangement (how it is structured), complexity (the number of levels), and integration (the degree to which it consists of discrete bits versus large networked clusters). Aspects of knowledge acquisition that were examined include attentional focus, cue recognition, pattern matching, information seeking, sources of information used, and interpretation and evaluation of information obtained. Problem identification and representation were studied in terms of aspects of the problem that received attention and the sequence in which those aspects received attention, ways in which aspects of the problem were explicitly identified and organized, goals identified by the problem solver, conditions identified with the problem, the relationship between aspects of the problem receiving attention and information seeking patterns, and resources used to obtain information or considered as potential operators for solving the problem. Problem solving processes were examined in terms of resources used as operators to solve the problem, the time needed to solve the problem, interpretations and evaluations applied to solution test results, the number of solutions generated, and effectiveness and acceptability of the results the solution(s) produced.

The two research studies entail a comparison of two sets of individuals, individually engaged in solving the same problem(s). One set of individuals is comprised of novices in the knowledge domain; the other set is composed of experts in the knowledge domain.

In their design, both studies drew heavily from the research literature on problem solving and novice-expert information processing. This research is mostly contained in the area of

cognitive science and is concerned with how the mind works in complex thinking and learning processes. Research on mental structures and processes underlying problem solving has been facilitated by the development of techniques for observing and analyzing these covert phenomena. The two research studies presented in this monograph incorporated a number of these techniques which include thinking aloud (Ericsson & Simon, 1984), stimulated recall (Calderhead, 1981) and protocol analysis (Ericsson & Simon, 1984). The two studies also illustrate different ways of recording data in this type of research, one study using audio tape, and the other using a combination of audio and video tape.

The literature reviews in the two study reports have been condensed to allow emphasis on the design, results and implications of the studies. A more thorough review of the literature underlying these studies can be found in the full report of each study, and in Thomas and Litowitz, (1986). Some findings from previous novice-expert comparison research regarding general differences between novices and experts is summarized below accompanied by a brief discussion of their relationship to findings from the two specific knowledge domain expertise studies reported here.

Relationship of Specific Knowledge Domain Expert-Novice Findings and General Characteristics of Experts and Novices

Previous research has indicated that novices and experts approach a problem solving situation differently and bring different resources to the task (Anderson, 1985; Chi, Fletovitch, & Glaser, 1981; Chi, Glaser, & Rees, 1981; Chiesi, Spilich, & Voss, 1979; Fredette & Lockhead, 1980; Glaser, 1985; Kozma, 1987; Lachman, Lachman, & Butterfield, 1979; Logan & Eastman, 1986; Newell & Simon, 1972; Norman, Jacoby, Geightner, & Campbell, 1979; Rasmussen & Jensen, 1974; Voss, Tyler, & Yengo, 1985.) Novices and experts appear to differ in what knowledge is stored in memory and in the structures in which that knowledge is stored. This difference was confirmed in both of the specific knowledge domain studies reported here. Further, expertise appears to be problem and context specific. An expert in one domain can be very much a novice in another domain.

Novices simply know less than experts. They have a smaller store of accumulated knowledge in memory than experts. This means that they must search externally for information that experts either hold in their heads or can generate from other information in the situation or in memory. Scott Johnson's study indicated clear quantitative differences between expert and novice trouble shooters' scores on knowledge tests and more random searching by novices for information from technical manuals and through surface examinations of faulty generators. Experts had more knowledge than novices did about the specific

electro-mechanical system with which they were asked to work. Betty Cooke's diagrams clearly indicate the quantitative as well as qualitative differences in the knowledge stores of expert and novice parents. Expert parents knew more about both their own child's unique patterns and about general child development principles than did novice parents.

Novices' knowledge is discretely structured. That is, it is not interconnected. Experts' knowledge, in contrast, is networked, and interwoven like a string ball or a piece of webbing, netting or mesh. This characteristic allows the expert to gain access to a much larger portion of knowledge stored in memory from activation or stimulation of just one part of the knowledge structure. This means the expert is more able than a novice to hold more key information in short term memory and recall more complicated events and elaborative detail. Further, it is thought that experts have the ability to transform their knowledge by recombining it and restructuring it so that it becomes more useful in a given situation. It is thought that novices' knowledge is stored in the form in which many textbooks and courses provide it - memorized concepts and principles relatively unconnected to each other or to actions, contexts or applications. On the other hand, experts' knowledge of concepts and principles (declarative knowledge) has been proceduralized or integrated with specifics of situations. Proceduralization occurs as a result of experience and practice through which declarative knowledge is embedded in occurrences, practices, specific instances and sequences of actions. Betty Cooke's diagrams of expert parents' mental processes and structures vividly illustrate proceduralized knowledge as integration of general and specific knowledge and the connection of knowledge to action.

Novices tend to focus on concrete, specific, surface characteristics in a problem, on those characteristics more readily apparent, and to categorize problems in terms of these surface features. Experts focus on deeper, principle-based and functional relationships in a problem and tend to see a problem as representative of a generalized set of problems characterized on the basis of more abstract concepts. While the novice may possess an unconnected series of discrete, cause-effect relationships, the expert possess long, interwoven chains of causal patterns. These characteristics assist the expert in recognizing patterns and relationships among variables and in noting complexes of variables all at once. It further enables the expert to connect stored knowledge about solution methods with the features and factors in a situation. To a novice many features of a situation are unique whereas to an expert, very few features are unique. Thus, experts bring deeper, more powerful and tested insights to bear on a problem and connect this knowledge of principles to the concrete situations they encounter. Scott Johnson's study clearly supports this

difference with data that shows novices' focus on directly observable characteristics of the generators and experts' hypotheses about nonvisible parts. Betty Cooke's data revealing experts' knowledge of their child's typical behavior patterns illustrates this characteristic.

Novices' knowledge is less complex than experts'. This means it has fewer levels in its structure. Research suggests that experts possess a large, hierarchically arranged knowledge structure specific to an area of expertise and containing many levels ranging from highly general, abstract concepts to highly specific instances. A way of picturing the complexity characteristic is to think of a very complex organization having many positions and levels within levels. An onion with many layers that peel away or a computer icon which opens into several icons each of which open into more and more icons are other metaphors for visualizing the complexity dimension. An expert can bring very powerful, general concepts to bear on specific situations and instances. Further, experts tend to form abstracted, low detail versions of a problem and not get mired down in specifics that prevent them from seeing an overall picture of a problem. The novice, on the other hand, being more focused on the details, is not as able to see the larger picture in which the problem fits. This difference was most vividly confirmed in Scott Johnson's data which indicated the ability of experts to make functional level interpretations from surface cues and the lack of this ability among the novices. Betty Cooke's study suggests that experts' more general, abstract knowledge is embedded in their knowledge of specific instances.

Novices have more difficulty than experts in discriminating relevant from irrelevant information. Consequently, novices are not so selective in identifying information to consider and must process much more information than experts. This extraneous information becomes a barrier to being able to focus on what is truly relevant and helpful in understanding and solving a problem. While the novice must allocate a higher proportion of their limited attentional and cognitive processing resources to irrelevant material, the expert is able to determine what to focus attention on based on what features are likely to be more informative. Scott Johnson's study illustrates this characteristic vividly by indicating how easily novices get "off the track" or never find the beginning of a path that will lead them to determine the location of a malfunction. Betty Cooke's study indicates that novice parents do not note cues that are critical to informing them about appropriate responses they might make to their child's behavior. Rather, they pay as much or more attention to other types of cues.

Experts have highly developed, largely automatic mental processing and control routines that enable them to be more efficient information acquirers and processors. The expert's

knowledge base contains a pattern recognition system which reduces the information processing load and provides a system of retrieval aids for accessing desirable courses of action (Chase & Chi, 1980, pp. 11-12, 14). They automatically recognize patterns in and features of a situation. It has been suggested that condition-action units, a central concept in Betty Cooke's study, may comprise such a system (Simon, 1980). Condition-action units are comprised of an action together with conditions specifying when the action is to be taken. They provide the expert with the ability to recognize when a given action will be useful. A condition action unit contains an if portion that focuses on conditions and goals or desired states and a then portion which specifies the action focused on operators that will achieve the goal or desired state. Because these control processes and processing routines have become automatic in experts, experts can use their scarce conscious processing resources for processing of unfamiliar or unusual aspects of a problem.

Many of the differences between the knowledge base, cognitive structures, and control and processing routines of novices and experts contribute to novices being slower than experts at solving problems. While Scott Johnson's time data on one of the two problems he incorporated in his study did not clearly indicate that experts were faster at finding faults, his hypothesis generation data vividly contrasts the efficient, controlled search and attentional focus of experts versus the random approach of novices.

The two studies reported in this volume clearly provide specific knowledge domain examples of more general findings regarding expertise. In order to design instruction intended to promote expertise within a particular knowledge domain, knowledge of the characteristics of expertise in the context of the knowledge domain is needed. These studies provide that knowledge for two domains as well as models for research that will yield similar knowledge for other domains. The two studies also reveal the power and applicability of general findings regarding expertise reported in the literature. Despite the differences in the problem areas represented by these two studies, expert and novice functioning in both studies revealed amazingly similar characteristics at a more general, abstract level.

It should be emphasized that both of the studies reported in this monograph looked at individuals at each end of the expertise continuum at one static point in time rather than examining developmental processes along the continuum. Research leading to an understanding of what happens mentally along the way as an individual moves from being a novice to being an expert is needed in order to more fully inform educational designs intended to promote expertise.

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CHAPTER 2

KNOWLEDGE AND SKILL DIFFERENCES BETWEEN EXPERT AND NOVICE SERVICE TECHNICIANS ON TECHNICAL TROUBLESHOOTING TASKS

Scott D. Johnson[1]

The diagnosis of malfunctioning equipment and machinery is an important facet in our industrial economy. This nation's quality of life is dependent upon the ability of our workforce to identify and solve technical problems. The service sector of the nation's economy, which has been steadily growing, is one source of the need for problem solving abilities in the workforce. As technology has advanced, so has the complexity of most equipment. As a result, it is becoming increasingly difficult for people to know all there is to know about repairing equipment and machinery. The knowledge and cognitive process skills that are used in troubleshooting and repair are becoming increasingly valuable. Industry's problem lies in the lack of understanding of the knowledge and skills that are required to perform the complex task of troubleshooting faulty equipment.

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[1]Scott Johnson is Assistant Professor of Industrial Education at the University of Illinois, Urbana-Champaign.

This chapter is a condensed summary of a more detailed report of this study available through Dissertation Abstracts International or from the Training and Development Research Center, University of Minnesota.

The author wishes to acknowledge the insightful comments and support throughout this project that were provided by Dr. Ruth G. Thomas, Director of the Higher Order Thinking Research Program in the Minnesota Research and Development Center for Vocational Education at the University of Minnesota and by Dr. Richard A. Swanson, Director of the Training and Development Research Center in the Department of Vocational and Technical Education also at the University of Minnesota. Thanks are also due to Allen Jacobsen, Training Manager of the Onan Service Training School, who provided the equipment and subject matter experts needed for this study.

This study was sponsored by the Minnesota Research and Development Center for Vocational Education and the Training and Development Research Center in the Department of Vocational and Technical Education at the University of Minnesota.

This study provides insight into the nature of expertise by comparing the cognitive and performance behaviors of expert and novice troubleshooters as they attempted to locate faults in technical systems. The study was divided into two investigations. The first investigation addressed the differences in the knowledge base that expert and novice troubleshooters bring to a problem. The second investigation examined performance differences between expert and novice troubleshooters.

Literature Review

Cognitive Task Analysis

The development of most training programs is based on incomplete task analysis models. One type of analysis model commonly used, behavioral task analysis, decomposes the task into observable behaviors. This provides the instructional developer with an understanding of the observable behaviors of troubleshooters but pays no attention to the internal workings of the troubleshooter's mind while solving problems. A second type of task analysis, rational task analysis, has been used to identify the thought processes of experts. This approach fails because it relies on the expert's retrospective account of the thought process used during troubleshooting (Magone & Yengo, 1986). The rational approach merely identifies the cognitive processes that the expert thinks are being used but does not necessarily result in the identification of the actual cognitive processes that were used during the solution of the problem (Ericsson & Simon, 1984).

This research study was based on a cognitive task analysis and resulted in a deeper and more complete understanding of both directly observable and indirectly observable troubleshooting behaviors. Gott (1986) described three arguments for the use of cognitive task analysis over either behavioral or rational methods. First, cognitive task analysis can capture more of the substructure of complex technical skills. Other task analysis methods cannot reveal these sub-skills because skilled performers, through automation of their skills, are often unable to accurately explain their actions (Polanyi, 1962). Second, cognitive task analysis can provide an "ideal" model to guide the development of technical instruction. Cognitive task analysis can reveal the expert's mental models for explaining system functioning while behavioral task analysis identifies performance without understanding (Kieras & Bovair, 1984; Magone & Yengo, 1986; White & Frederiksen, 1987). Third, the use of cognitive task analysis concerns the adaptiveness of instruction to the needs of the learner. With a cognitive task analysis, highly individualized instructional decisions can be made as learners progress from concrete representations of surface or physical features to abstract representations of the functional and operational features of a problem.

Knowledge Organization

Current theory suggests that an expert's knowledge is organized very differently from that of a novice. Verbal protocols of experts and novices who were engaged in solving elementary physics problems showed that, while both groups have rich knowledge bases related to physical configurations and properties, experts have additional knowledge related to the problem solution based on major laws and principles (Chi, Glaser, & Rees, 1982). Egan and Schwartz (1979) conducted a similar study of the influence of expert and novice knowledge structures on the subjects' ability to recall symbolic drawings. Subjects from each group were asked to review electrical drawings and were later asked to reconstruct the drawings from recall. The results showed that when presented with drawings that had random placement of electronic devices in a circuit, the experts performed no better than the novices. However, when presented with realistic drawings, the experts were able to recall significantly more of the drawing than the novices. Their study suggests that the memory of expert electronic technicians was based on "conceptual" chunks. Therefore, experts were able to recall portions of the drawings as chunks of information (i.e., amplifier circuit, tuner circuit, etc.) rather than as individual components.

Cognitive structures have also been looked at as forms of schemata or mental models. Schema theories suggest that the knowledge structure or schema of individuals allows them to mentally trace information through their cognitive structures (Anderson, Spiro, & Anderson, 1978). Kieras and Bovair (1984) were interested in determining what role mental models play in learning how to operate an unfamiliar piece of equipment. In this case, the mental model relates to the understanding of the device in terms of its structure and processes. The results of the study suggest that a mental model is not needed for procedures that are very easy. For more difficult procedures, the mental model is used to provide specific inferences about what the operating procedures must be. Other studies have investigated the importance of mental models for developing an understanding of technical systems and to aid in troubleshooting faulty equipment (Bouwman, 1983; Lajoie, 1986; Logan & Eastman, 1986; White & Frederiksen, 1987).

Investigation of Knowledge Differences

Common sense tells us that expert troubleshooters know more about the equipment they work on than do novices. Because experts are able to bring more knowledge to their troubleshooting situations, they are able to work more efficiently and effectively. The purpose of the first investigation was to specifically identify the knowledge differences between expert and novice technical troubleshooters.

Subjects

The subjects selected for this study were classified as either expert or novice based on their amount of relevant education, years of experience on the job, and supervisor ratings. Five novice subjects were selected from a group of service technicians who were enrolled in the Small Products Training course delivered by the Onan Service Training School in the winter of 1987. The Onan Service Training School has a 25 year history of providing instruction in the service, maintenance, and repair of the generator sets manufactured by Onan Corporation. The students who attend the Service Training School come from all areas of the United States and are typically employed by distributors and dealers of Onan Corporation products. The novice subjects were service technicians who diagnose and repair faulty generator sets as a major portion of their normal work. These technicians had several years of experience with mechanical and electrical equipment, although they averaged only one-half year of experience in repairing generators.

The expert group consisted of five factory service representatives who were involved with the manufacturing and repair of generators at the factory level. These expert technicians averaged over ten years of experience in repairing equipment with electrical, mechanical, and generator systems.

Apparatus

The equipment used for this study was electric generator sets. Electric generator sets are used to supply electrical power for many applications including building standby systems, boats, recreational vehicles, and contractors' job sites. A generator set is a highly technical piece of equipment that requires service technicians to have very specialized knowledge and skills in the electrical, mechanical, and magnetic domains. As with any technical device, breakdowns occur that must be repaired by qualified and experienced personnel. If generator sets cannot be quickly repaired, expensive and potentially dangerous situations can occur.

Method

The purpose of this investigation was to identify the knowledge differences that expert and novice technical troubleshooters bring to a problem situation. Two measures were developed with the assistance of subject matter experts and were pilot tested for reliability and validity. The first measure was used to quantify the subjects' knowledge of the basic principles that underlie the operation of a generator set. The subjects were questioned about the basic electrical, mechanical, and magnetic principles and concepts that relate to the operation of

generators. The second measure, a 20-item test of system understanding, was used to quantify the subjects' understanding of generator systems. The subjects were asked to identify system parts, describe their operation and function, and describe the relation of each part to the system as a whole.

Several other measures were used to identify differences in the technical abilities of the service technicians to make technical tests, use technical manuals, read schematic and wiring diagrams, and use mathematical formulas.

Results

The data collected showed clear differences in the amount of knowledge that expert and novice troubleshooters bring to a problem situation. The experts knew more about the mechanical, magnetic, and electrical principles and theories that underlie the operation of generators than the novices as shown in Table 1.

Table 1

Raw Score Means, Standard Deviations, and t-Test Values for Basic Principles Exams

		Group[a]				
		Expert		Novice		
Exam	Items	M	SD	M	SD	t
Mechanical	14	10.20	.84	6.60	1.14	5.69*
Magnetic	13	10.80	1.92	7.40	1.14	3.40*
Electrical	14	13.00	1.22	4.80	2.39	6.83*
Total	41	34.00	2.92	18.80	3.70	7.21*
Formulas	10	8.80	1.30	.40	.89	11.88*

df = 8.
[a]n = 5 for each group.
*p < .01.

On the 20-item System Understanding Exam, the experts answered significantly more questions correctly than the novices.

The raw mean score for the expert group was 18.0 and for the novice group was 11.8. A two-sample t-test indicated that these mean scores were significantly different ($t = 6.39$, $p < .01$, $df = 8$). Each subject was asked in an interview to identify system parts, to explain their operation and function, and to describe the part's relation to the entire system. While both groups were able to identify most of the generator parts and were able to provide a description of the function and operation of the parts, the descriptions provided by the novices were not as specific and detailed as were those of the experts. The novices were able to talk about how switches and starters work only in general terms, while the experts talked specifically about a particular switch or starter on a particular type of generator. Differences in the depth of system understanding were identified. When asked to describe the operation of the generator as a whole system, the novices provided scanty accounts about the generation of electricity in a generator. In contrast, the experts delivered lengthy and detailed accounts about how generators produce electricity. Several of the experts went beyond the requested information and described how design modifications in the various parts and assemblies have affected the operation and efficiency of the generator.

In addition to identifying differences in the system knowledge of the experts and novices, this investigation also sought to identify differences in the procedural skills that troubleshooters bring to a problem. These skills include the ability to obtain information from technical documents, to perform mathematical calculations, and to trace current flow on schematic drawings.

As indicated in Table 2, no difference was found in the ability of the two groups to obtain information from service and parts manuals. However, significant differences were found in their abilities to solve technical problems using mathematical formulas. Each subject was given ten generator-related mathematical word problems to solve. The experts were able to solve 96% of the problems, while the novices were able to solve only 34% of the problems. Even after the novices were given the appropriate formulas to use they were able to solve only 62% of the problems.

Technical troubleshooters often need to trace current flow on schematic drawings as they attempt to find problem faults within a technical system. In order to accurately trace current flow on schematic diagrams, troubleshooters must understand the function and operation of the individual parts within the system and the relation of the parts to the system as a whole. They must also be able to differentiate between the various types of circuits on the schematic drawing itself. As a measure of this ability, each subject was given a schematic drawing of a generator set and was asked to trace the circuits that carry

Table 2

Raw Score Means, Standard Deviations, and t-Test Values for Procedural Knowledge Measures

		Group[a]				
		Expert		Novice		
Exam	Items	M	SD	M	SD	t
Service Manual	6	5.20	1.29	4.75	2.28	1.29
Parts Manual	9	8.80	2.19	7.60	1.14	2.19
Calculations	14	9.60	5.40	3.40	2.51	5.40*

df = 8.
[a]n = 5 subjects in each group.
*p < .01.

battery current, alternating current, and ground while the unit is in operation. The experts were significantly more likely to have traced all three circuits correctly as is indicated in Table 3.

Summary

The results from this investigation show that experts have a much greater depth of understanding of the basic principles and concepts that underlie the operation of generator sets. Experts can also comprehend the function and operation of the generator system. On the other hand, the novices seemed to lack an accurate "mental model" of the operation of a technical system they repair daily. It appears that one key to the development of technical troubleshooting expertise can be found in the troubleshooter's depth of system understanding. To further investigate the nature of technical troubleshooting expertise, a second investigation was conducted.

Table 3

Raw Score Means, Standard Deviations, and t-Test Values for Missing Lines of Circuit Tracing Measure

	Group[a]				
	Expert		Novice		
Exam	M	SD	M	SD	t
Battery	3.40	3.85	13.80	7.16	-2.86*
Ground	1.80	1.30	10.00	6.44	-2.79*
Alternating Current	.80	.84	12.00	3.46	-7.03**
Total	6.00	4.47	36.20	15.61	-4.16**

df = 8.
[a]n = 5 subjects in each group.
*p < .05. **p < .01.

Investigation of Performance Differences

The purpose of this second investigation was to identify differences in the actual troubleshooting performance of the expert and novice service technicians. For this study, troubleshooting performance was defined as the ability to effectively acquire and interpret information and to generate, evaluate, and accept appropriate hypotheses. This involved investigating both directly observable performance and indirectly observable performance.

Technical Preparation

The Problem Solving Behavior Research Model (Johnson, in press) requires that three components be thoroughly examined: the problem, the problem solver, and the problem solving process. An understanding of each of these components is necessary in order to achieve an accurate description of problem solving behavior.

The Problem

A cognitive task analysis was used to identify the placement of faults that could potentially be installed into the generator

sets. After a careful review of the possible faults, two problems that occur infrequently and are hard to diagnose were selected. Their unfamiliarity and their difficulty requires the troubleshooters to invoke cognitive processes from a deeper level of knowledge than would problems that occur frequently or are easy to diagnose. The two selected problems would be caused by a faulty fuel pump or an open wire between a printed circuit board and the starter solenoid.

The Problem Solver

As described in the literature review, the knowledge base of the expert is organized much differently from that of the novice. Newell and Simon (1972) recognized that a major limitation in the problem solving ability of individuals was their limited memory capacity, which in turn affected the quantity of data they could manage during problem solving. Novices are aware of all the facts and procedures that are required to solve a problem, but because of their limited short term memory capacity, they are able to focus only on specific, individual components of the problem. In contrast, the expert, through chunking of information, is able to hold more information in the short term memory and thereby operate more efficiently and effectively.

The organization of expert knowledge is an important factor in the problem solving performance of troubleshooters. Current theory suggests that human memory consists of two parts: (a) knowledge bits, and (b) the organization of those knowledge bits (West, Fensham, & Garrard, 1985). To better understand the cognitive structure of the troubleshooting subjects in this study, a cognitive map was developed through the cognitive task analysis. This cognitive map represents the expert's knowledge of the generator system and shows the physical and conceptual components within a generator as well as the relationships between the components. The map was used to aid in analyzing the troubleshooters' behaviors as they worked to identify the generator faults.

The Problem Solving Process

In many types of problem solving the final solution is apparent and specific, which results in the problem solver using one of several common problem solving methods. However, in troubleshooting, where the final solution is neither apparent nor specific, the problem solver is more likely to use a hypothesis testing method (Sweller & Levine, 1982). Other research on technical system troubleshooting and diagnosis problems support this inference (Bouwman, 1983; Elstein, Shulman, & Sprafka, 1978). Through a synthesis of these and other studies found in the problem solving literature, a Technical Troubleshooting Model was developed (Johnson, 1987). As shown in Figure 1, this model describes the troubleshooting process from an initial acquisition

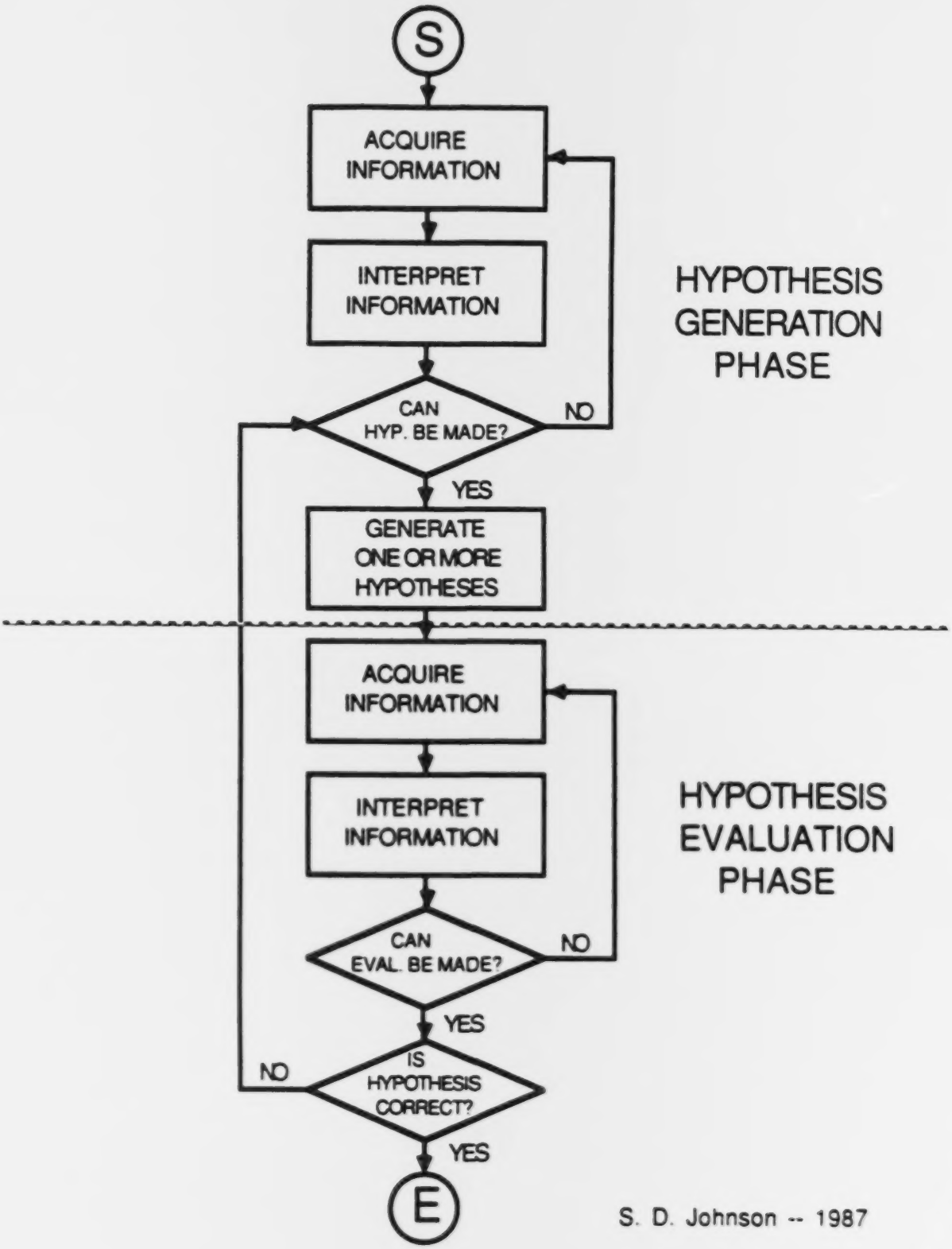


Figure 1. Technical Troubleshooting Model.

of symptoms, through the generation and evaluation of potential hypotheses, to the identification of the fault.

Method

Verbal protocols were used to analyze technical troubleshooting performance. Subjects were instructed to "think aloud" as they worked through a problem. These verbalizations were recorded using an audio cassette recorder and were later transcribed for analysis. Prior to collecting the actual protocols, the subjects were given several practice exercises to help them become comfortable with thinking out loud (Ericsson & Simon, 1984).

Following the practice exercises, each subject was presented with two generator sets. One had a faulty fuel pump, and one had an open wire. These faults had been installed previously by the investigator. The subjects had available to them all the necessary equipment and materials needed to solve the problems including schematic and wiring diagrams, test equipment, and technical manuals.

The verbal protocols for each novice and expert subject were systematically segmented and coded. A quantitative micro analysis and a qualitative macro analysis of the data were performed to determine patterns related to information acquisition and interpretation and hypothesis formulation and evaluation.

Results

All of the experts were able to find the faults in both generator sets. The novices were not so successful. Only three of the five novices were able to find the fault in the fuel pump problem, while only two were able to find the open wire. The novices were allowed to continue searching for the fault until they felt it was useless to continue or until a 45 minute time limit had been reached. In only one of the five unsuccessful attempts was the time limit reached.

The time-to-solution data shows that the problem type is an important factor in the performance of technical troubleshooters. The novices who solved the fuel pump problem, which was mechanically based, were able to complete the task faster than the experts (novices averaged 6.3 minutes, *SD* = 3.79, to problem solution while experts averaged 11.4 minutes, *SD* = 5.86). The experts were able to solve the wire problem, which was electrically oriented, almost five times faster than the novices (experts averaged 7.2 minutes, *SD* = 4.89, while novices averaged 33.5 minutes, *SD* = 16.26). The novices' knowledge and experience in the mechanical domain seemed to be an important factor in

their successful completion of the faulty fuel pump troubleshooting task.

It was found that the experts were more likely to rely on test procedures than the novices. However, there appeared to be no difference in the ability of the subjects to perform the procedural tests they selected.

The coded protocol data revealed patterns regarding information acquisition, information interpretation, hypothesis generation, and hypothesis acceptance variables. Through the use of the coded protocol segments, it was possible to conduct both a qualitative and qualitative analysis of the data. The following section presents results of the quantitative analysis.

Quantitative Analysis

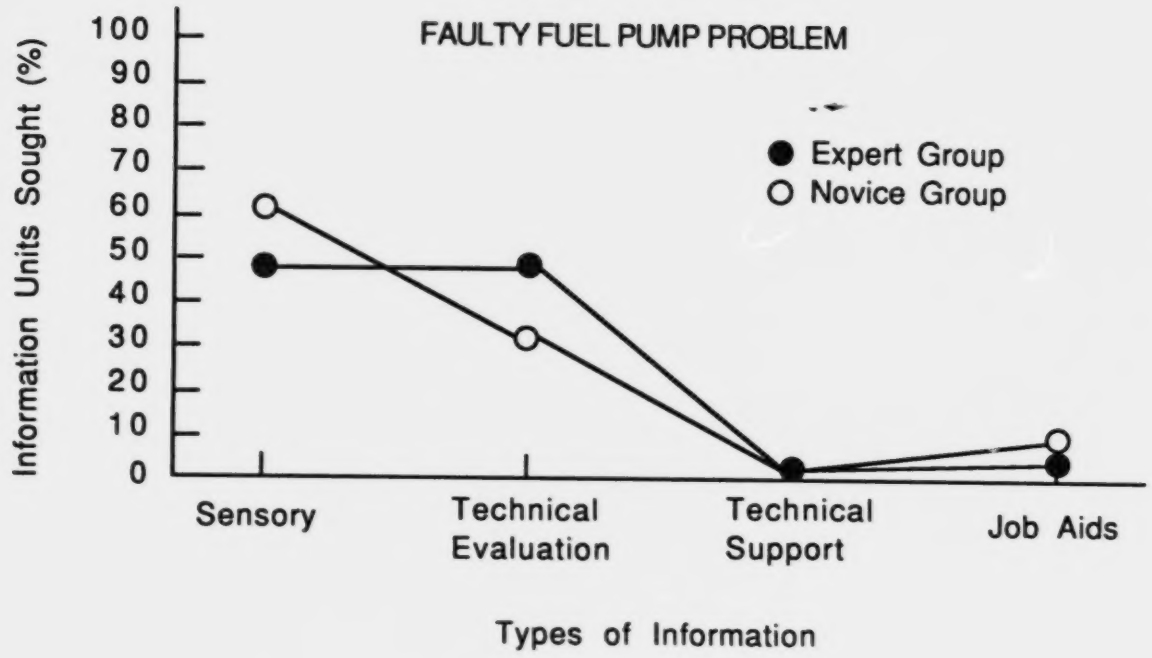
Information Acquisition

The information acquisition segments were analyzed to determine the types of information sought, the nature and relevancy of the information, and the success of the subjects in obtaining desired information.

Figure 2 provides a graphic representation of the types of information sought by the two groups of subjects. From these data it is clear that on both types of problems the experts sought information by technical evaluation means more than the novices. Novices sought information by sensory means more than the experts. The data show little or no apparent difference between the groups in the search for information in the job aids and technical support categories.

In Figure 3 it can be seen that the experts and novices differed in the nature of information sought. Experts sought specific information while the novices looked for more general information. These data hold true on both problems although a greater difference was found on the wire problem. Of the information the experts sought on the fuel pump problem, 81.8% was specific while 73.3% of the information novices sought was specific information. On the wire problem 81.0% of the information sought by experts was specific while only 62.9% of information novices sought was specific.

For the relevancy of information variable it was found that the type of problem influenced the groups (see Figure 4). On the fuel pump problem, over 90% of the information sought by both groups was relevant. However, on the wire problem, which was a harder problem for the novices, the experts sought 97.6% relevant information while the novices sought only 61.4% relevant information.



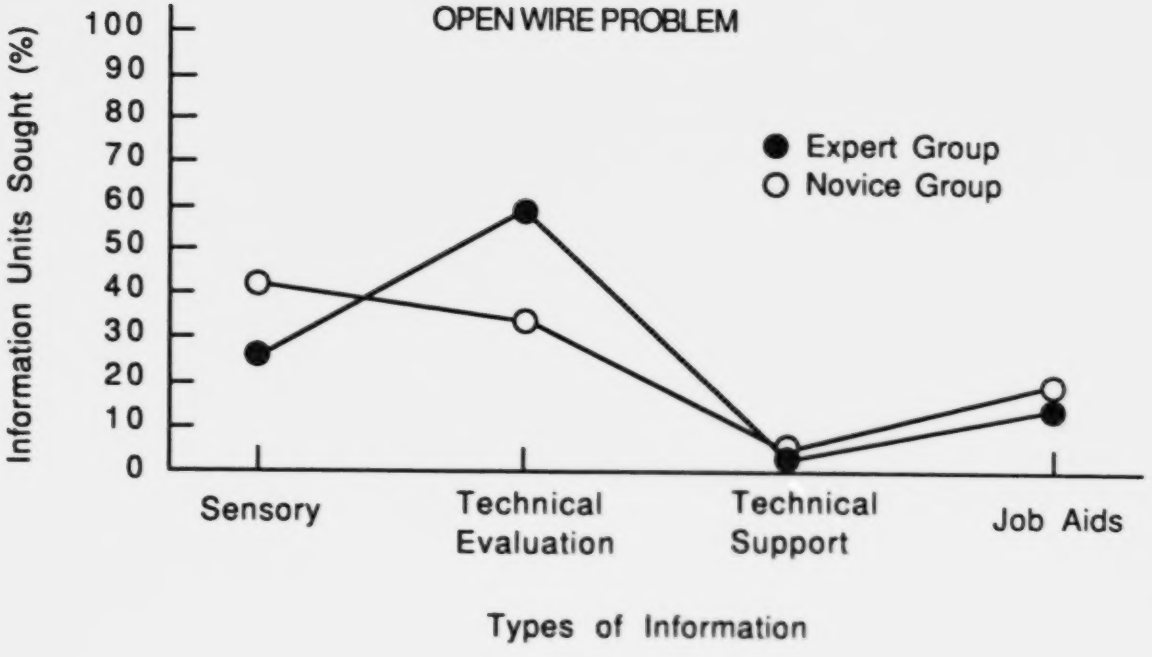


Figure 2. Types of Information Sought During Troubleshooting.

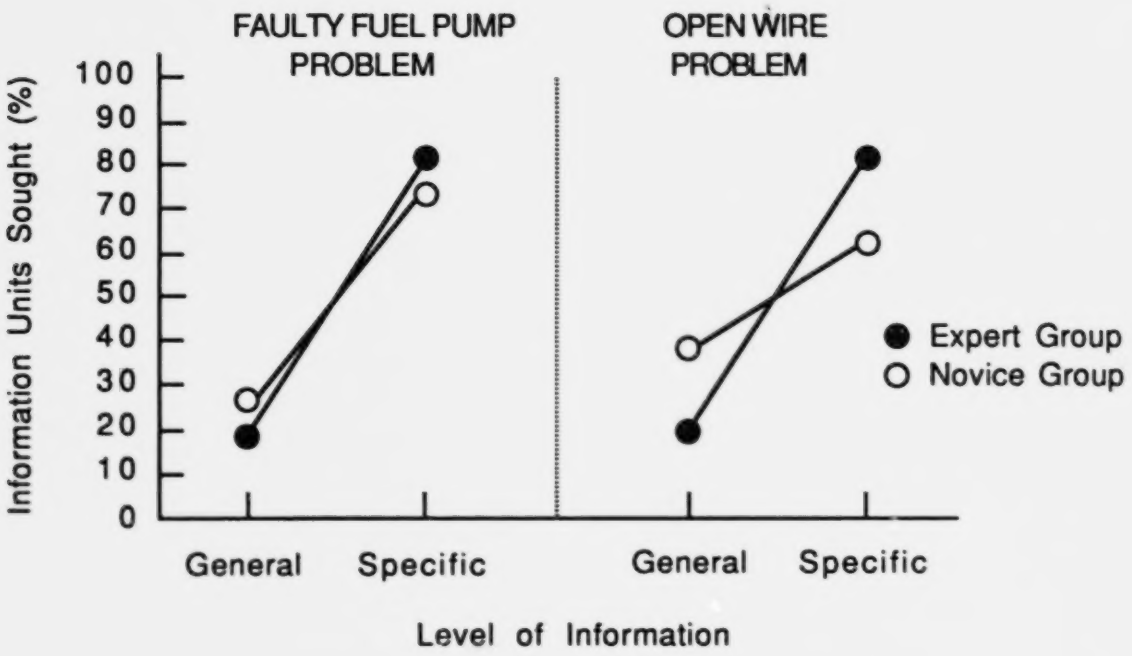


Figure 3. Level of Information Specificity

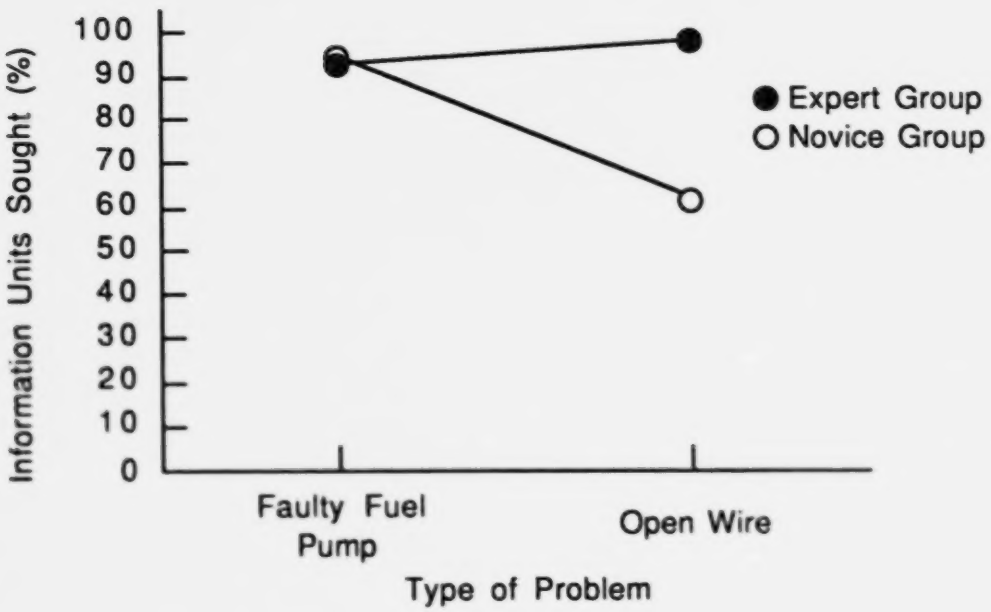


Figure 4. Relevancy of Information Sought During Troubleshooting.

With respect to effectiveness in obtaining information, once again the type of problem was found to influence the information acquisition process. As shown in Figure 5, it was found that the groups differed slightly on the fuel pump problem but greatly differed on the wire problem. On the fuel pump problem both groups were able to obtain over 90% of the information they sought. This was not the case on the wire problem where the experts obtained 100% of the information they sought while the novices could only obtain 73.6% of the information they sought.

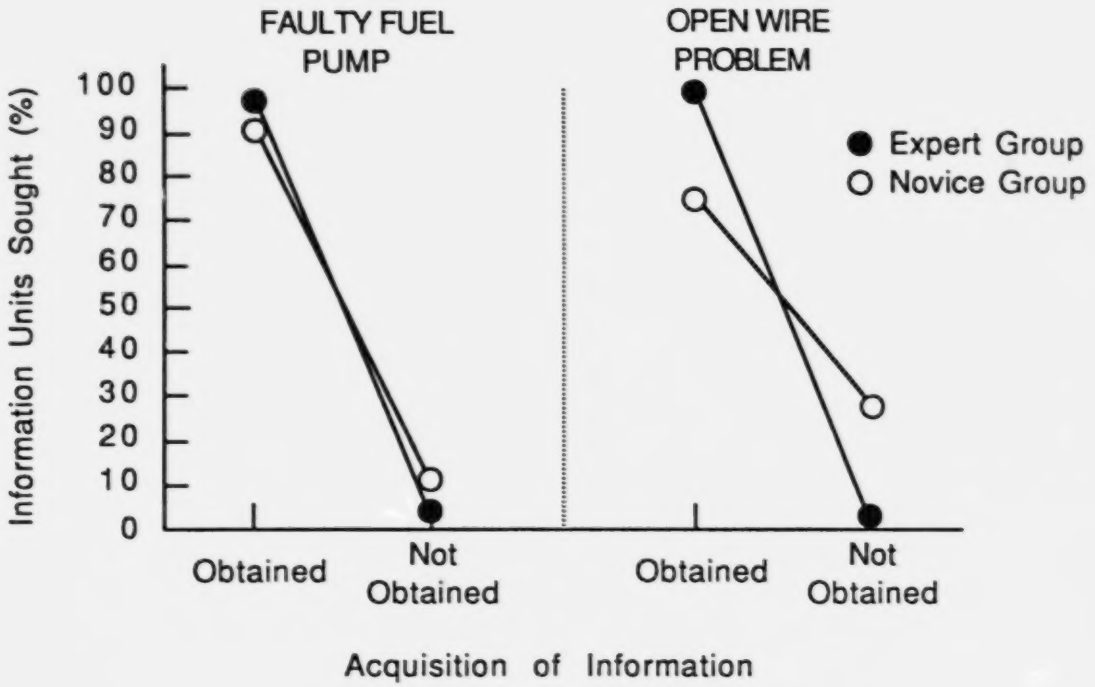


Figure 5. Effectiveness in Obtaining Information.

Information Interpretation

Following its acquisition, the information must be interpreted by the subjects. The information interpretation variables include the level of interpretation and the accuracy. Information can be interpreted at two levels: description and meaning. Of the verbal interpretations that appeared in the subject protocols, both groups had more descriptive than meaningful interpretations. However,the data do not provide a clear picture of the differences in group's information interpretations (see Figure 6).

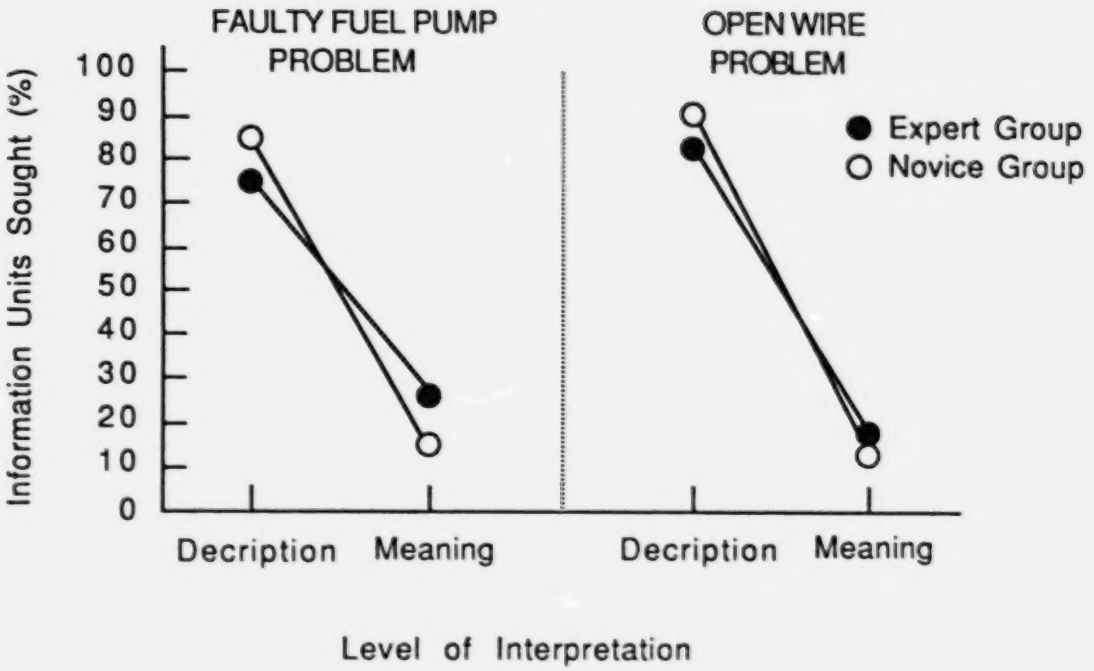


Figure 6. Level of Interpretation of Acquired Information.

On the one hand, the novices produced slightly more descriptive interpretations than the experts. On the fuel pump problem, the experts had 75.9% descriptive interpretations while the novices had 84.1%. On the wire problem, the experts had 81.4% descriptive interpretations while the novices had 89.1%. On the other hand, the experts provided more interpretations of the meaning of the information than the novices. Of the verbal interpretations that were made by the experts, 24.1% were meaningful interpretations on the fuel pump problem and 18.6% were meaningful on the wire problem. The novices generated 15.9% and 10.9% meaningful interpretations, respectively.

The other variable of interest in this section is the accuracy of the interpretations. As in the level of interpretation data, little difference was found in the ability of the groups of interpret information. The experts accurately interpreted 99% of the information on the fuel pump problem and 98% on the wire problem. The novices accurately interpreted 98%

of the information on the fuel pump problem and 93% on the wire problem.

Hypothesis Generation

Following the acquisition and interpretation of information, the Technical Troubleshooting Model shows that troubleshooters generate one or more potential faults or hypotheses. Hypotheses are generated until a correct one is obtained. The variables of interest for the hypothesis generation phase of the troubleshooting process include the total number of hypotheses generated, the relevancy of the hypotheses, and the hypothesis selection criteria that are used. The coded protocol statements provide the data needed to examine differences between the two groups of subjects.

Regarding the number of hypotheses generated, once again the type of problem seemed to affect the performance of technical troubleshooters. As shown in Figure 7, the groups did not differ on the fuel pump problem but greatly differed on the wire problem. On the fuel pump problem, both groups generated 29 hypotheses. The experts generated 24 hypotheses while the novices generated 61 hypotheses on the wire problem.

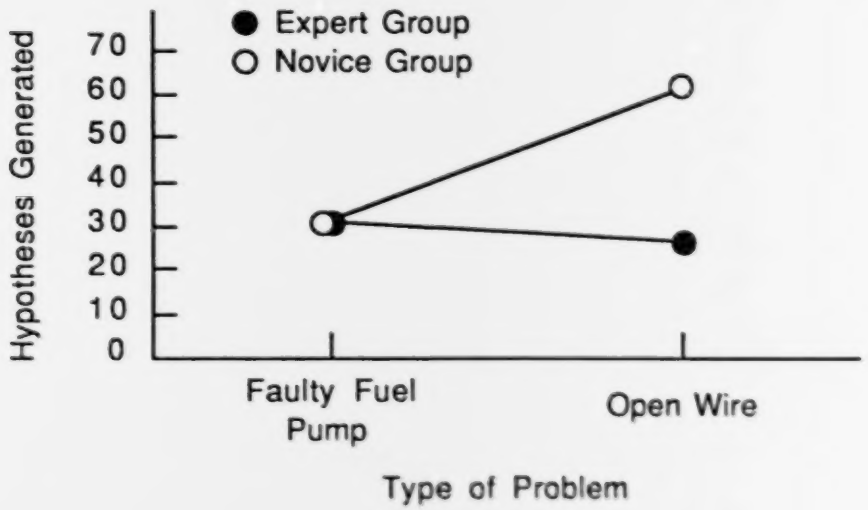


Figure 7. The Number of Hypotheses Generated.

As was found on the data for the total number of hypotheses generated, the groups differed slightly on the relevancy of the hypotheses generated on one type of problem while they differed

greatly on the other (see Figure 8). On the fuel pump problem both groups generated primarily relevant hypotheses. The expert

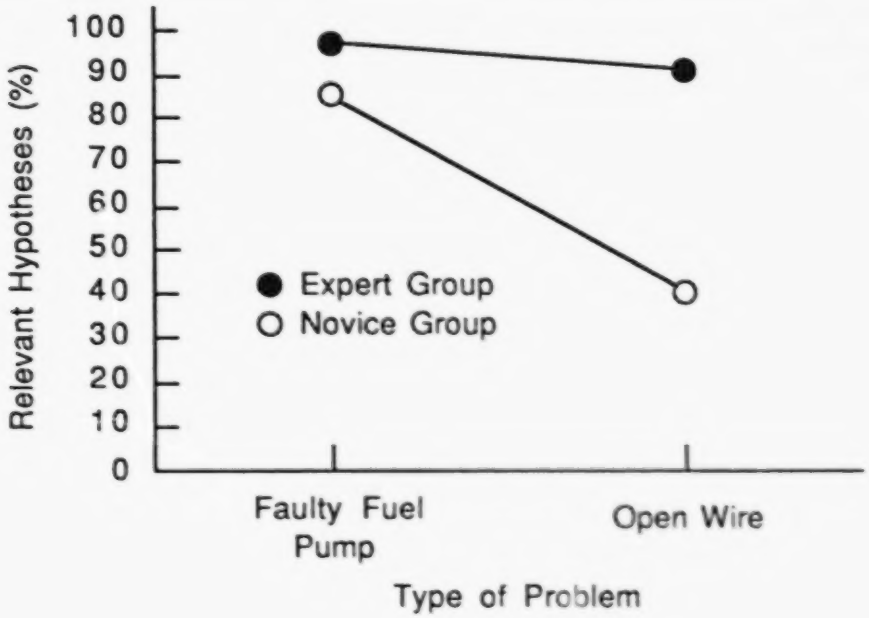


Figure 8. The Relevancy of Hypotheses Generated.

group generated 96.6% relevant hypotheses and the novice group had 86.2% that were relevant. On the wire problem, the experts generated 91.7% relevant hypotheses while the novices generated only 41.0% relevant hypotheses.

In summary, the quantitative analysis of the protocol data highlighted the differences between expert and novice troubleshooting performance. The experts were very purposeful in their troubleshooting behavior. They knew what specific types of information were needed to find the fault, and they were most likely to obtain their information through some form of technical test. Virtually all of the information the experts obtained was relevant to the problem and they were able to generate logical and relevant hypotheses that could be checked through additional technical tests.

In contrast, the novices more often exhibited a trial and error approach to troubleshooting. They typically sought general information through sensory checks (i.e., sight, sound, smell, touch). Seldom did the information obtained in this manner serve to reduce the size of the problem. It did not help them in generating potentially accurate hypotheses.

Qualitative Analysis

Beyond the quantitative description of the above processes, it was deemed valuable to analyze the troubleshooting protocols qualitatively. A clearer understanding of the troubleshooting activities of the experts and novices was gained through a qualitative analysis of the subject's initial problem formulation, development of the problem space representation, and sequence in working through the problem space.

Problem Formulation

One of the first steps in the problem solving process is the initial problem formulation. Following the identification of the initial problem symptoms, the troubleshooter can determine what additional information is needed and what the potential fault might be. In this study, the subjects varied in the amount of information they were able to gather regarding the initial conditions of the problem. The protocol data suggest that the expert troubleshooters were able to gain much more information from the initial problem symptoms than were the novices. For example, following an initial attempt to start the faulty generator, Expert 1 stated:

> I can feel the fuel pump pumping so I know that I do have voltage to my fuel pump. Therefore, that means my circuit board is good, am applying voltage, at this time I know that the fuse is good, and it gives me a pretty good indication that I do have battery power. At this time I don't know if it's enough because of the fact that the fuel pump draws less current than the starter does.

From the initial symptom of the fuel pump clicking on the wire problem, this expert was able to determine that there was battery power going to the printed circuit board and the fuel pump and that the fuse and battery were likely in working condition. Contrast the above protocol with that of Novice 1:

> We'll push the start button. Ah. I get nothing. Um. I'm just gonna kind of look around, take a look at it for a minute.

The other novices also did not verbalize any of the initial conditions. As shown in the protocols, they attempted to start the unit, discovered it would not start, and then began checking various parts of the generator for problems. This lack of a clear problem representation seemed to prevent the novices from selecting an appropriate plan for troubleshooting.

Problem Space Representation

Following the acquisition of the initial problem conditions, problem solvers must develop a problem space (Newell & Simon, 1972). In a troubleshooting task, troubleshooters use the problem space to help guide them in the selection of hypotheses that will lead to the identification of the fault in the system. In order to graphically represent the subjects' selections of relevant hypotheses, problem space maps were developed. The scatter graph in Figure 9 shows the location of the hypotheses that were generated by both groups on the wire problem. The lightly shaded areas of the map represent the actual problem space for this problem based on the initial symptoms of the generator. It is within this shaded area that the potential faults could occur. Each circle and square in Figure 9 represents one hypothesis that was generated and evaluated by a subject, and its placement on the problem space map provides a clue as to the nature of the hypothesis. It appears that all the experts were able to represent the problem space accurately based on the initial problem symptoms. The majority of the troubleshooting checks and all the hypotheses made by the experts were located within the problem space (shaded areas). It can also be seen that the novices generated numerous hypotheses that were outside the true problem space. The lack of accurate problem space representations forced the novices to use more random trial and error approaches rather than the purposive approaches used by the experts.

Problem Solution Sequence

Clear differences in the subjects' sequences through the problem space can also be shown through graphic representations. Figure 10 depicts the sequence of hypothesis selection on the problem behavior map of Expert 1 on the wire problem. After determining the initial symptoms of the problem, Expert 1 used the acquired information to direct him to the sub-system that most likely contained the fault. Expert 1 then proceeded in a logical and efficient sequence of behaviors to reduce the size of the problem space until the problem was reduced to only one possible fault.

The novices proceeded through the problem space in a completely different manner. As Figure 11 shows, the sequence through the problem space by Novice 1 is a seemingly random pattern. The novice gathered an enormous amount of irrelevant information. Because of this irrelevancy of information, the novice was unable to reduce the size of the problem space and could not focus in on the fault. All of the experts exhibited similar efficient and logical behavior while all of the novices appeared to employ the more random approach. For a complete collection of all the subject's sequences through the problem spaces see Johnson (1987).

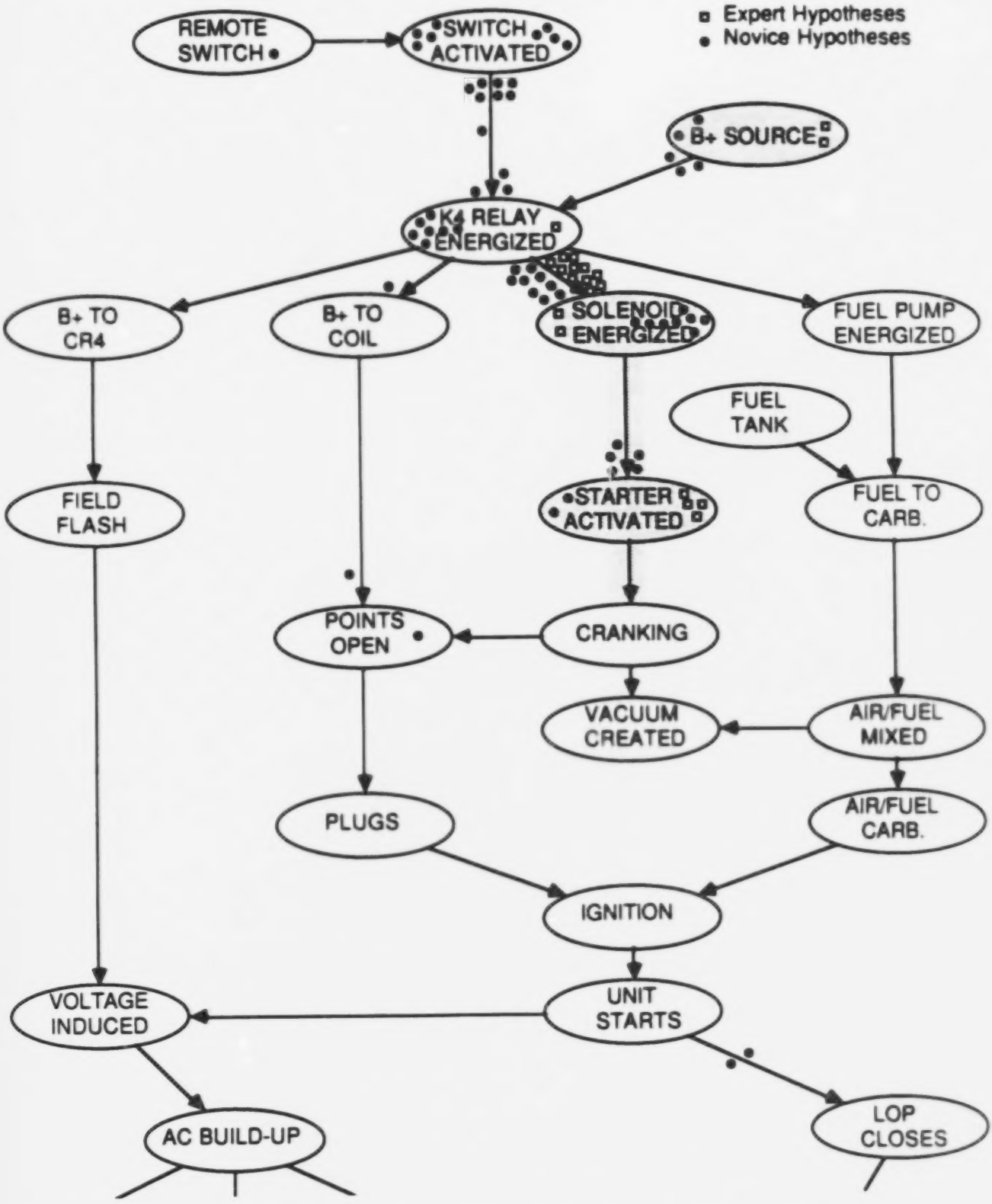


Figure 9. Group Problem Space Map for Wire Problem.

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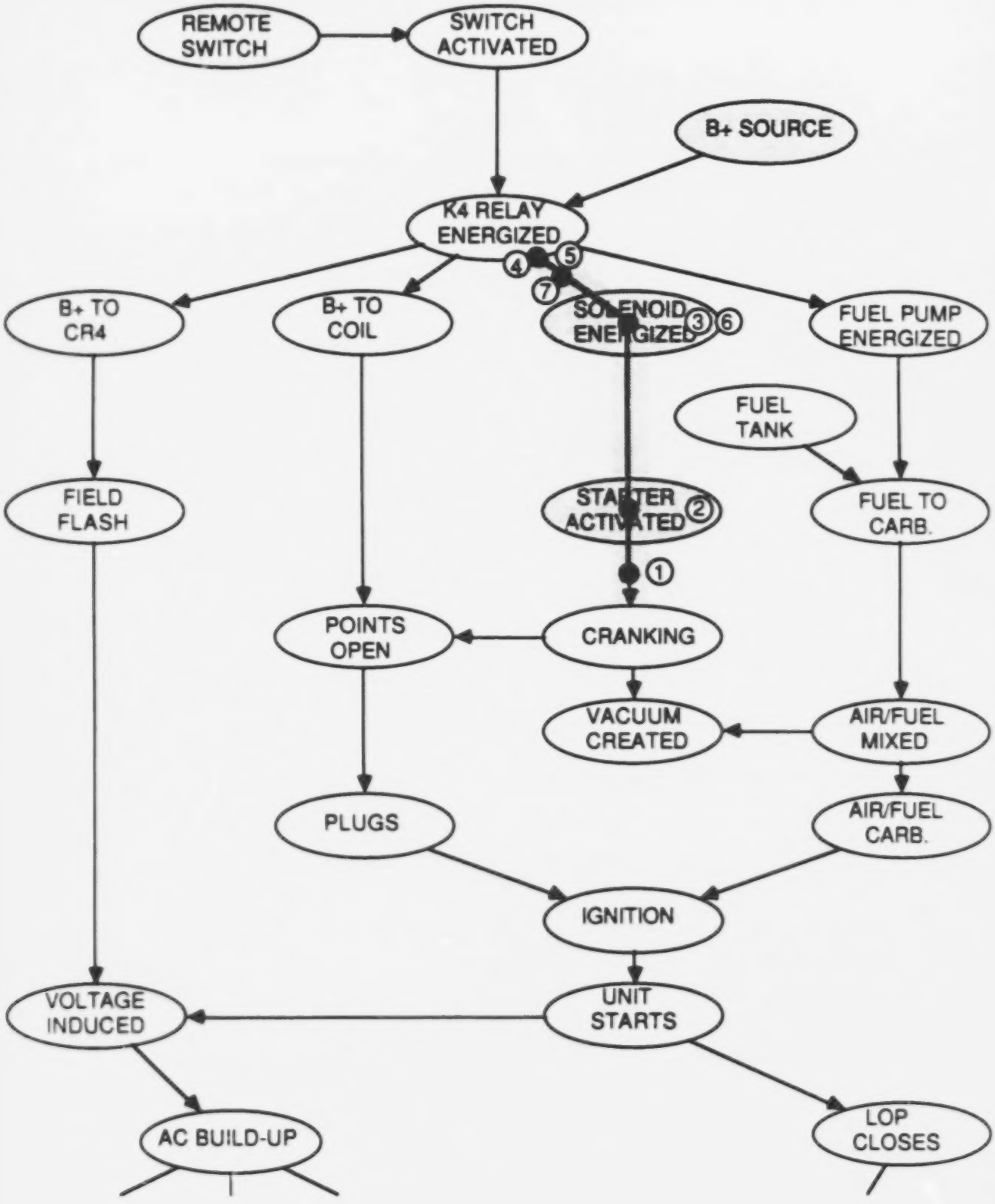

Figure 10. Expert 1 Problem Behavior Map on Wire Problem.

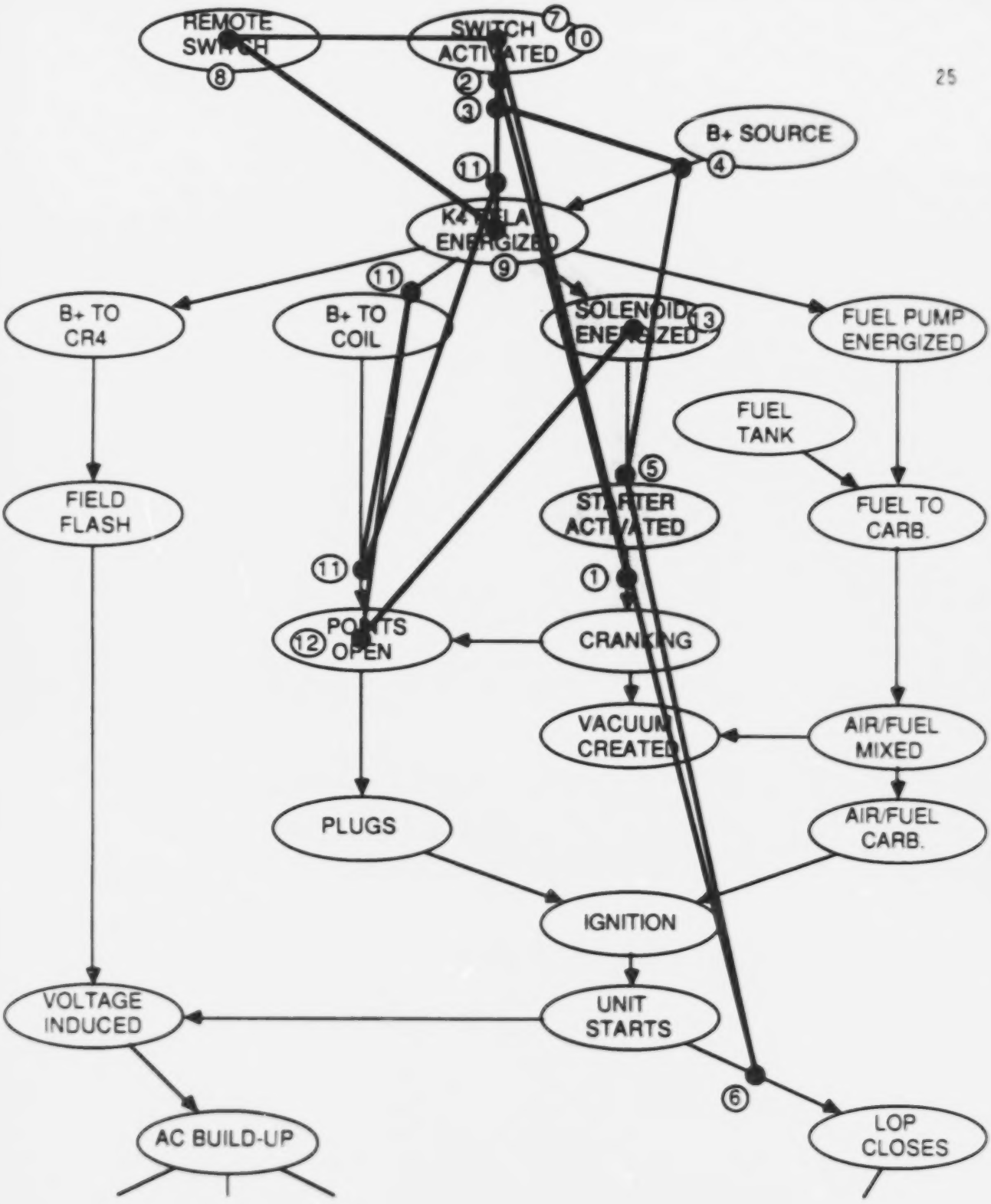

Figure 11. Novice 1 Problem Behavior Map on Wire Problem.

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Summary

The results of this second investigation show definite differences between the experts and novices. The primary difference between the troubleshooting performance of experts and novices was that the experts were able to select better information and generate better hypotheses. There appears to be little or no difference between the abilities of the novice and expert troubleshooters to acquire and interpret most types of information, to perform procedural tests, or to generate and evaluate hypotheses. The major difference lies in the types of information acquired, the types of procedural tests performed, and the types of hypotheses generated.

While other factors may also be involved, it appears that the two major reasons for the experts' superior skills lie in the amount and the organization of their knowledge. Through the organization of their knowledge base, the experts were able to efficiently access their knowledge and match the information cues they observed with those in their knowledge base. Their ability to recognize patterns from past experience allowed the experts to make the right decisions regarding the types of information to acquire and the types of hypotheses to generate.

In contrasting experts' behavior with that of the novices it becomes clear that the novices had not acquired the same amount of knowledge as had the experts. Also, because of their lack of experience, the novices did not have their knowledge efficiently organized. This lack of organized knowledge prevented the novices from "seeing" the patterns on which the experts seemed to rely so heavily. The novices began with the same initial symptoms but were often unable to determine what the important symptoms were, and even when they were able to do so, the novices did not come any closer to the fault. Hypotheses were generated but they were not necessarily based on previous information. Hypothesis selection by the novices did not seem to be closely aligned with any logical or efficient strategy. Further, the novices attempted to verify their hypotheses with weak, unreliable, sensory-dominated tests.

Conclusions, Recommendations and Implications

A major goal of training is to provide trainees with knowledge and skill and to guide them in the development of expertise. Before we can begin to design effective technical training programs we need to have a deep understanding of the knowledge and skills that are required to troubleshoot technical systems. This study was an attempt to provide that necessary understanding through the investigation of differences between expert and novice service technicians who troubleshoot technical equipment. From the results of this study, it is obvious that there are clear differences between expert and novice technical

troubleshooters. We now must use the results of this study to design training programs that will reduce those differences.

Conclusions and Recommendations

This study illuminates three areas that can be emphasized to improve technical instruction. First, for technical instruction to be effective, the content domain must be adequately and completely defined. The domain boundaries, the structure of the domain, and the content within the domain must be identified. This study provided one example of a complete analysis of a technical domain. The cognitive task analysis identified the three sub-domains within the larger domain of generators and the important content within each sub-domain. The cognitive task analysis also provided a broad description of the technical system through the development of a system map which graphically represented the mental model that the expert troubleshooters used to identify system functions and relationships.

Second, technical instruction must include content specifically related to the technical system being studied. Trainees must be taught the function and operation of the technical system. They must comprehend the relationships between the individual parts and the total system. Instructors must be aware of the need for trainees to develop accurate mental models of the system and should explicitly teach an idealized mental model. Instruction must also cover the technical evaluation procedures that are likely to be needed. Trainees must know what procedures are available, when they should be used, how they are done, and what the results mean.

Third, tecnnical instruction must provide trainees with realistic learning experiences. Trainees should be presented with systems that do not function properly and asked to work through the troubleshooting process to identify system faults. This experience should be formalized in a manner that requires the trainees to record initial symptoms, desired information, potential hypotheses, and useful technical evaluations. Instructors will be able to identify mistakes and omissions in the trainees' records of their problem solving processes. Realistic learning experiences will provide trainees with opportunities to develop and strengthen their understanding of systems and to integrate formal knowledge with practical experience. It is through practice that the organization of knowledge and the development of patterns occurs. Without such practice it is doubtful that the transformation from novice to expert troubleshooter could take place.

Implications for Further Research

Three areas of need for further research can be identified. First, further research regarding expertise is definitely needed.

This study showed that troubleshooting performance is related to the amount of knowledge and experience of the troubleshooter. It also appears that troubleshooting expertise may not be widely transferable. A troubleshooter who performs as an expert on one type of system may perform as a novice on another. Because of lack of consistency across types of technical systems, the knowledge and skill requirements for each system for which training is designed should be studied.

Second, further investigation into the structure of the knowledge of expert troubleshooters is needed. Through the cognitive task analysis approach, research into the organization of expert knowledge can be completed. The identification of the patterns and mental models that experts have developed through years of experience can provide important insight for designing learning experiences for trainees.

Third, further investigation into the methods of teaching troubleshooting skills is needed. This study has provided an understanding of troubleshooting expertise that can be used to develop better training programs. Research that identifies instructional techniques and learning experiences that are most effective for developing troubleshooting skills is likely to improve instructional design in training and development.

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CHAPTER 3

MENTAL PROCESSES AND KNOWLEDGE UNDERLYING EXPERTISE IN PARENTING

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Interest and programming in parent education is expanding in many states and promises to continue based on a number of factors including increasing evidence that the family has a critical impact upon a child's development and that traditional supports are no longer available to many families. As the field of parent education has expanded, demands for training and professional development opportunities for the educators for these programs have increased. In the process of planning and delivering professional development offerings for parent educators, it has become increasingly clear that more needs to be known in answer to the question "What makes an effective, competent parent or caregiver?" Until a clearer understanding of this question is available, parent educators are limited in what they can offer to parents as effective parenting approaches, and trainers of parent educators are limited in their ability to most effectively prepare these educators.

The observable actions or behaviors of human beings have typically been the focus of study in understanding parental competence. Little is known about the mental processes and knowledge that underlie parental behaviors, i.e., the thought processes that "go on inside a parent's head" and knowledge affecting parents as they decide and act in situations with their children. Much of the cognitive activity that underlies parental

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behavior likely involves conscious and unconscious problem solving processes. The problem solving tasks that have been the focus of research in human problem solving (Anderson, 1985; Frederiksen, 1984; Newell & Simon, 1972) have largely been well-structured problems with definite, singular solutions such as math and logic problems. Problem solving focused on more ill-defined human problems in which all information is needed for problem definition and solution is not available and which involve choosing among multiple potentially effective solutions has received far less attention (Frederiksen, 1984).

This research contributes to understanding the nature of the cognitive processes and knowledge content and structures involved in everyday, ill-defined human problems, specifically in problems relevant to the parental role. Problems parents encounter in daily interactions with their children are not static, well-structured, and defined problems. The mental processes and knowledge structures of expert and novice parents in relation to their performance in a problem solving situation with their infants were examined and compared as a basis for development of instructional design for increasing parental competence. In addition, methodology for conducting such a study was developed.

Literature Review

Cognitive psychology theory and research in information processing and human problem solving (Anderson, 1985; Lachman, Lachman, & Butterfield, 1979; Newell & Simon, 1972) form the basis of this study. Because cognitive psychology is focused on studying human thought structures and processes, it is relevant to human behavior in many contexts, including everyday life. Research that enables understanding of thinking in everyday life contexts will support educators' efforts to strengthen people's expertise in dealing with their everyday life challenges.

Knowledge Content and Structure and Mental Processes

The distinction is made in cognitive psychology between knowing that or declarative knowledge and knowing how or procedural knowledge. Declarative knowledge is knowledge about facts and things. Procedural knowledge consists of knowledge about how to perform various cognitive activities and knowledge about the skills a person knows how to perform.

Knowledge is thought to be structured in the memory of an individual in organized relationships among concepts called schemas. Schemas are a kind of "knowledge network" and are thought to guide the storage and retrieval of knowledge, the generalization and interpretation of ideas, and the initiation and regulation of action (Messick, 1984). The term script is

used to describe a stored predetermined sequence of events that define a well-known situation or episode (Shank & Abelson, 1977; Anderson, 1985). Through a process referred to as pattern recognition and matching, schemas and scripts enable a person to match single features or cues or chunks of features or cues in descriptions or experiences they encounter with a stored set of features or chunks in order to identify and interpret these descriptions or experiences (Thomas & Litowitz, 1986).

The organization and structure of knowledge provided by schemas are what allow relevant knowledge to be found in memory. The skill of expert problem solvers arises from the completeness and complexity of their schemas (Chi & Glaser, 1985). A person is thought to have a strong schema if it is based on a large store of principle-driven knowledge in a particular knowledge domain (Anderson, 1984). Knowledge a person has of specific instances based on frequent experience with everyday events is thought to be made more accurate and elaborated through the availability and complexity of related domain knowledge (R. G. Thomas, personal communication, January 8, 1988). Memory systems, attentional capacity and allocation, and the context of events and experiences also have been found to influence cue and cue pattern recognition and interpretation and the storage and retrieval of knowledge (Anderson, 1985; Kahneman, 1973; Lachman, Lachman, & Butterfield, 1979; Rogoff, 1984).

Research on human problem solving has led to the development of a general theory of problem solving which assumes that humans operate as an information processing system when they carry out the mental processes involved in problem solving that produce their behavior (Newell & Simon, 1972). An episode of problem solving is characterized by three essential features: goal directedness, subgoal decomposition, and operator selection. Behavior is clearly organized toward a goal, the original goal is decomposed into subgoals or subtasks, and an operator or action that will achieve a goal is selected. The solution of the overall task or problem is a sequence of these operators or actions toward achievement of subgoals (Anderson, 1985; Newell & Simon, 1972).

The best way to solve a problem is to devise the best problem representation. Effective problem representation involves a process in which the problem solver is forced to be explicit about the desired goal and to carefully identify the steps necessary to reach the goal. The mental representation of a problem is likely to include condition-action units which specify an action together with conditions under which the action is to be carried out (Anderson, 1985). Condition-action units allow rapid recognition of situational cues that signal the appropriateness of particular actions (Simon, 1980).

Nature of Problems and Problem Solvers

Problems have been most commonly categorized as being either well-defined or well-structured, or ill-defined or ill-structured (Frederiksen, 1984; Greeno, 1980; Newell & Simon, 1972). A problem is thought to be well-defined if a definite goal is evident and a test exists to determine if a proposed solution is, in fact, a solution. An ill-structured problem is one for which the goal is usually vague or unspecified and there are more complex and less definite criteria for determining when the problem has been solved (Frederiksen, 1984; Newell & Simon, 1972; Thomas & Litowitz, 1986). There seems to be agreement in the literature that there is no fundamental difference between the cognitive processes used in solving well-structured and ill-defined problems and that they are better conceived of as representing positions on a continuum than a dichotomy (Frederiksen, 1984; Greeno, 1980; Simon, 1978). Most problems encountered in everyday life are of the more ill-defined type. Greeno (1980) emphasized the need to "have some relatively complete analyses of problem solving in some genuinely ill-structured problems" (p. 21).

With regard to problem solvers, there are clearly individual differences in information processing and problem solving styles which may be identified in such constructs as learning style, cognitive style, temperament, etc. (Thomas & Litowitz, 1986). The literature in cognitive psychology also reflects increasing focus on the study of differences in novice and expert information processing and problem solving and the process of developing novices into experts. Experts have been found to possess a larger and more complexly organized body of stored knowledge in content areas relevant to a problem than novices. Experts are more efficient and automatic than novices in their attentional focus and mental processing routines. Experts are more skilled than novices in their ability to represent problems and recognize patterns in a problem. And experts are better able to apply their knowledge than novices because their declarative knowledge is tightly bound to conditions and procedures for its use (Glaser, 1985; Messick, 1984; Thomas & Litowitz, 1986).

Implications of Parental Action for Children

Since the research reported in this study focuses specifically on effective parental action, a brief review of the literature related to the impact of parental action on children, particularly with respect to mothers and infants, is useful. Much research on mother-infant interaction has indicated that sensitive and responsive parental behavior is a predictor of child competence and attachment. Parental sensitivity is considered to be a determinant of individual differences in infant cognition and has been linked with children's exploratory behavior, goal directedness, cognitive performance, curiosity,

and problem solving (Lamb & Easterbrooks, 1981). Maternal behaviors that have been found to be indicators of sensitivity in parenting include prompt and appropriate responsiveness to the infant's signals and communications, availability and reliability of emotional comfort, and nonrestriction of exploration (Ainsworth, 1967, 1973; Clarke-Stewart, 1977; Sroufe & Waters, 1977; Kostelnik, Stein, Whiren, & Soderman, 1988). Infants and young children have been found to develop a sense of being in control when their parents are responsive to them, noting their signals and taking them into account when interacting with them (Maccoby, 1980).

Research Methods in Cognitive Psychology

The analysis of verbal protocols has become a sort of hallmark of the information processing approach (Newell & Simon, 1972). Ericsson and Simon (1984) have done extensive work on the use of verbal reports as data in understanding information processing and problem solving. They view verbal behavior as one type of recordable behavior that should be observed and analyzed like any other behavior. Two forms of verbal reports have been the primary data sources for verbal protocols. One, believed to be direct verbalization of specific cognitive processes, is known as concurrent verbal reports or "talking aloud" or "thinking aloud" (Ericsson & Simon, 1984). In such reports, information attended to is thought to be verbalized directly. The second form of verbal report is a retrospective verbal report in which information attended to is accessed, at least in part, from short-term memory just after the task or retrieved from long-term memory and verbalized. The term "stimulated recall" has been used to denote a particular type of retrospective verbal report in which audio or videotapes of a subject's behavior are used to aid a subject's recall of their thought processes at the time of that behavior (Calderhead, 1981).

Protocol analysis (Ericsson & Simon, 1984; Hayes, 1981; Simon & Simon, 1979) is the term used to describe the process of making inferences from verbal data by segmenting and coding the verbal reports. This process is based on the assumption that information rather than cognitive processes is what is attended to in information processing. Therefore, the processes themselves are not encoded directly from verbalizations but must be inferred.

A number of approaches (Glaser, 1985; Newell & Simon, 1972; Novak & Gowin, 1984; Shank & Abelson, 1977) which have been used for visually representing the internal mental states of individuals provide a means for better understanding the knowledge structures and cognitive processes used by an individual as they act to solve problems. Any or all of the methods just described can be used together to gain the most comprehensive and accurate information.

Investigation of Mental Processes and Knowledge Structures

In order to examine and compare the mental processes and knowledge content and structures of expert and novice parents, interview data and verbal records or protocols were collected through the use of three data collection approaches during two visits to the homes of five expert and seven novice mothers of infants 6-10 months old. The subjects selected for the study were classified as either experts or novices based on their amount and type of experience with children, their amount of relevant education, and recommendations from professional parent educators that they were either expert or novice parents.

Research Procedures

An audiotaped, semi-structured pre-task interview was conducted during the first visit to each subject to identify subjects' knowledge of their own child, their knowledge concerning child development and child rearing, and the relationship between these two kinds of knowledge; to identify subjects' expectations and goals for their child and their beliefs about their parent role; and to determine the subjects' experience with children, their education related to child development, and their sources of knowledge related to their parent role. During the problem solving task and stimulated recall interview with the subjects at the second visit, data were collected that yielded information about cues noted and recognized by the subjects in the situation, concepts/schemas and condition-action units activated by the cues, goals and subgoals of subjects for the outcome of their efforts in the situation, the attentional focus and actions of the subjects in the situation, and subjects' beliefs about the parent role.

The actions of the mothers and their infants were observed and videotaped during the problem solving task. The task consisted of giving each mother a basket of toys to use to engage the interest of her infant for approximately 15 minutes. In order to identify the knowledge structures and mental processes a mother was using, each mother was asked to "think aloud," i.e., to report out loud what she noticed and was thinking as she interacted with her infant. Audiotaped stimulated recall interviews were conducted with the mothers immediately following the videotaped parent-child activity. Each mother viewed her videotape with the investigator in segments with pauses at the end of each segment to ask the mother what she had been thinking and what was happening in each segment of the situation.

Data Coding and Analysis

The audiotapes of the pre-task interviews were transcribed, and content analysis procedures from communication research (Berelson, 1954) and from ethnoscience research in educational anthropology (Dobbert, 1982; Spradley, 1979) were used in the analysis of the interview data. These interviews were analyzed to extract the subjects' specific knowledge of their child, their knowledge in the domain of child development, their expectations or goals for their child, their beliefs about their role as a parent, their past experience with children other than their own, their formal education related to children, and their perceived sources of knowledge for their role as parents.

The verbal records or protocols of the parents' "thinking aloud" during the problem solving task were analyzed using protocol analysis procedures developed and recommended by Ericsson and Simon (1984). These procedures involved transcribing the audio portion of the videotapes, segmenting these verbal protocols into units by each short pause in the recorded protocols, coding the units, and identifying the sequences, function, and structure of the units and the thought processes revealed by the verbal record. After transcribing and segmenting the verbal portion of the videotapes, the videotapes were carefully viewed in order to insert descriptions of the behaviors of the mother and child immediately preceding and following the mother's verbal statements within the segmented "thinking aloud" protocols. These descriptions were done to aid the coding process by indicating the cues available to the mother from her infant and the situation, to note the mother's response or lack of response to the cues, to note the child's response(s) to the mother's actions and the situation, and to set the general context for the activity. Before coding each of the segmented phrases in the "thinking aloud" protocols, the stimulated recall interview audiotapes were transcribed and inserted along side the portion of the segmented "thinking aloud" protocols to which they referred.

After preparation of the video and audiotaped data in the manner described, each codable segment of each subject's "thinking aloud" protocol was coded according to categories indicating instances of cue recognition, cue interpretation, or instances in which the subject was indicating a subgoal(s) for the particular portion of the activity (see code categories in Table 1). The descriptions of the behaviors of the mother and child immediately preceding and following the mother's verbal statements during "thinking aloud" and the mother's statements during stimulated recall were referred to in the coding process to add accuracy to the coding of each "thinking aloud" verbal segment. The stimulated recall interview data was also content analyzed for indication of the parent role categories identified from the content analysis of the pre-task interviews (See Table 2

Table 1

Code Categories for "Thinking Aloud" Protocols

Cue Recognition

RB ..... Recognition of child behavioral cue--a statement made by the mother reflecting recognition of a behavioral cue given by the child.

RT ..... Recognition of toy or task/situation cue--a statement made by the mother reflecting recognition of a toy characteristic, movement, sound, etc. or a task/situation element.

Cue Interpretation

IB ..... Interpretation of child behavior using knowledge of own child--a statement made by the mother reflecting her interpretation of a cue(s) from the child based on stored knowledge she has of her own child's behavior.

IT ..... Interpretation of toy or task/situation--a statement made by the mother reflecting her interpretation of a situational cue(s) based on stored knowledge she has related to the physical object or element.

Subgoals for Task

CS ..... Child subgoal--a statement made by the mother reflecting the goal/desire of the child to act based on the mother's interpretation of cues given by the child.

PSC ..... Parent subgoal, child-focused--a statement made by the mother reflecting her goal/desire for the child to act based on what she sees as the child's need (response to cue given by child or situation).

PSP ..... Parent subgoal, parent-focused--a statement made by the mother reflecting her goal/desire for the child to act based on what would meet the mother's needs in relation to the child or situation (response is not seemingly related to cue given by child or situation).

Table 2

Role as Parent Categories from Pre-Task and Stimulated Recall Interviews

Guide	Indirect guidance or direction given to child; responding to or anticipating child's needs and cues; designing or setting the environment for the child; setting out or introducing objects or activities for the child; attempting to stimulate the child's interest; encouraging, supporting, or helping the child; distracting the child; limiting own involvement with the child.
Reinforcer/limit setter	Praising child or saying "no"; taking objects away; giving positive or negative feedback.
Fellow player	Joint use of toys or attempt to do so; efforts to get child to interact or play with the parent.
Teacher	Direct guidance in the form of attempting to teach the child something; direct instruction.
Verbalizer	Reflector; describer; stating or saying what child is doing or possibly thinking or feeling as the child acts; giving words to actions.
Model	Doing an activity or using an object.
Shower	Holding something up to or in front of the child; getting something out to give to or show the child.
Observer	Watching; seeing; noticing; wondering about or observing the child's behavior or activities; appears like or looks like child is doing or wanting something.
Caregiver	Feeding or diapering child; having child rest or sleep; showing concern for child's safety.
Nurturer	Being there for child; loving and comforting child; holding, cuddling, hugging child.

for the role as parent categories). In addition, overall task goals indicated by each subject for the problem solving activity were identified in the simulated recall interviews and coded as to whether they were child-focused or parent-focused.

In order to more clearly and completely represent the mental processes and knowledge content and structures operating during the problem solving activity and their interrelationships, the data collected during and immediately following the task were further analyzed by drawing out the connections between these processes and structures. Toy use episodes were selected from the subjects' verbal protocols for this analysis to identify relationships between the external environment and the subjects' internal mental structures and processes.

Results

Results of quantitative and qualitative analyses of the problem solving protocols are reported in the following subsections identified by the characteristic of the parents' knowledge and thought processes the data revealed.

Specific and Domain Knowledge

The content analysis of the pre-task interview revealed that the experts indicated more specific knowledge of their child and more domain knowledge in child development than did the novices. An average number of 35.8 statements per subject of specific knowledge of their child were made by the experts, in contrast to 10.6 such statements per subject made by the novices. The statements made by the experts included an average of 22.29 instances per subject of child development concepts, whereas the statements of the novices included an average of only .85 instances per subject of these concepts.

Goals for Child and Beliefs About Roles as Parent

In response to the interview question about their goals or expectations for their infant, all of the expert parents had child-focused goals, while the novice parents expressed some goals that were child-focused and some that were more parent-focused. Consistent with the findings on specific and domain knowledge just described, the goals of the experts for their child reflected domain knowledge in child development and were developmentally appropriate. The goals of the novices for their child, on the other hand, did not reflect knowledge of child development and were not always developmentally appropriate.

The subjects' expressions of their beliefs about their role as a parent in the pre-task interview differed between the novice and expert parent groups. The roles of guide, nurturer, fellow

player, observer, and caregiver were the roles most frequently reflected by the expert group (see Figure 1). The roles most frequently reflected by the novice group were fellow player, caregiver, nurturer, guide, and reinforcer/limit setter. The greatest difference between the expert and novice groups occurred in the frequency with which they expressed beliefs about their parent role in the guide category, experts mentioning the guide role more than twice as often as novices.

Experience, Education, and Sources of Knowledge

The experts had much more education and experience with children than the novices. All of the experts had at least a bachelor's degree in a field related to children and families, whereas none of the novice parents had any post-secondary education related to children. The experts reported a higher number of sources of knowledge available to them than did the novices.

Goals for Task

Consistent with the general goals and expectations for their child findings from the pre-task interview, the goals the expert subjects stated for the outcome of the problem solving task were child-focused and developmentally appropriate. Task goals stated by the novice subjects were more parent-centered. The experts indicated that their goal was to let their child choose toys that interested them or to introduce their child to different toys and observe their child's responses. The novice task goals reflected more of what they wanted to have happen in the situation rather than focusing on their child's needs and interests.

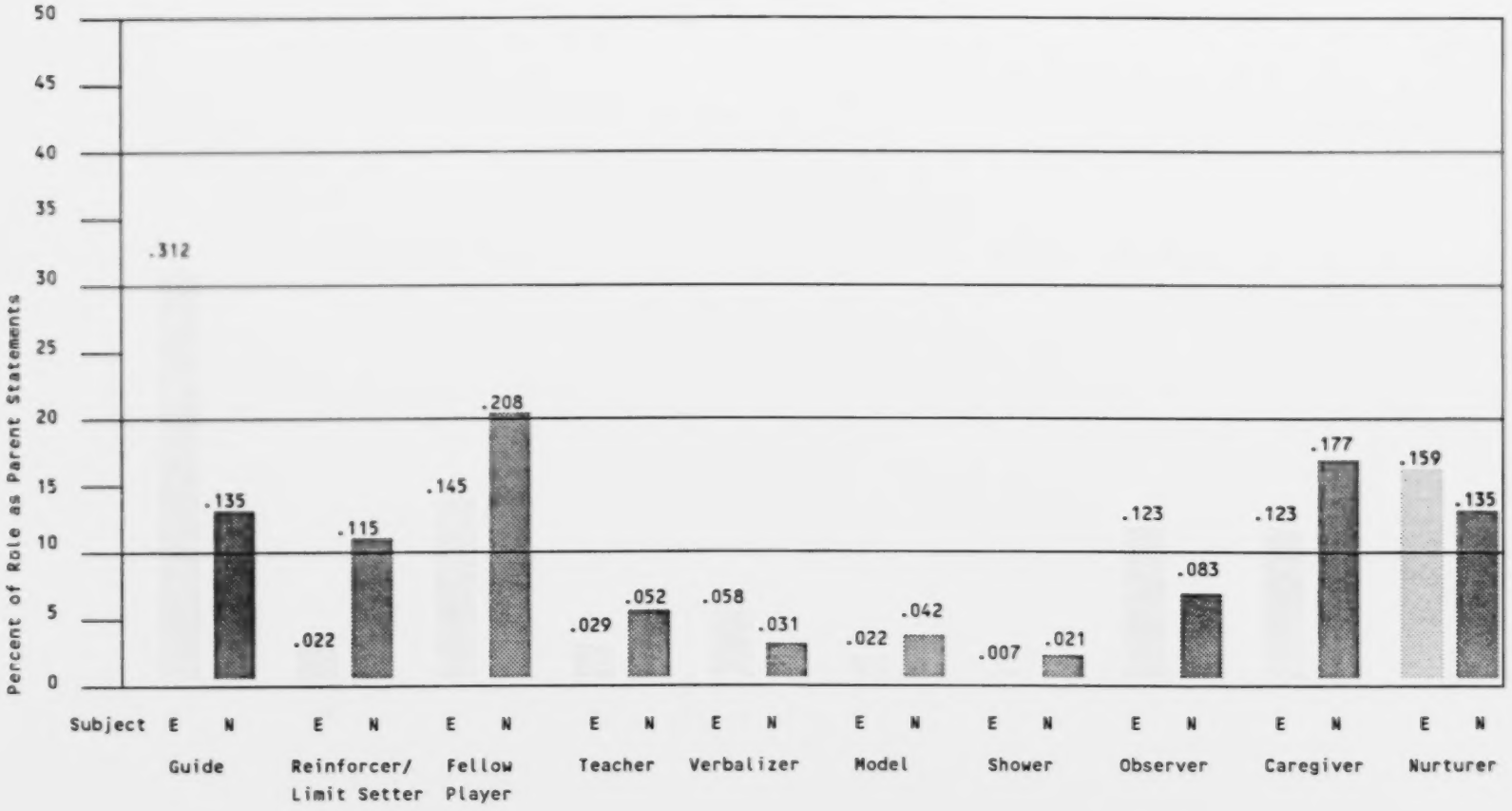
Knowledge Content and Structure and Thought Processes

Data collected during and immediately after the problem solving task were analyzed both quantitatively and qualitatively to infer the mental processes and knowledge content and structures revealed by the subjects as they engaged in the problem solving activity. This analysis was divided into three parts: (a) indication of cue recognition and interpretation and task subgoals, (b) expression of parent roles during the stimulated recall interview, and (c) representations of components of the knowledge structures and thought processes.

Cue Recognition, Cue Interpretation, and Task Subgoals

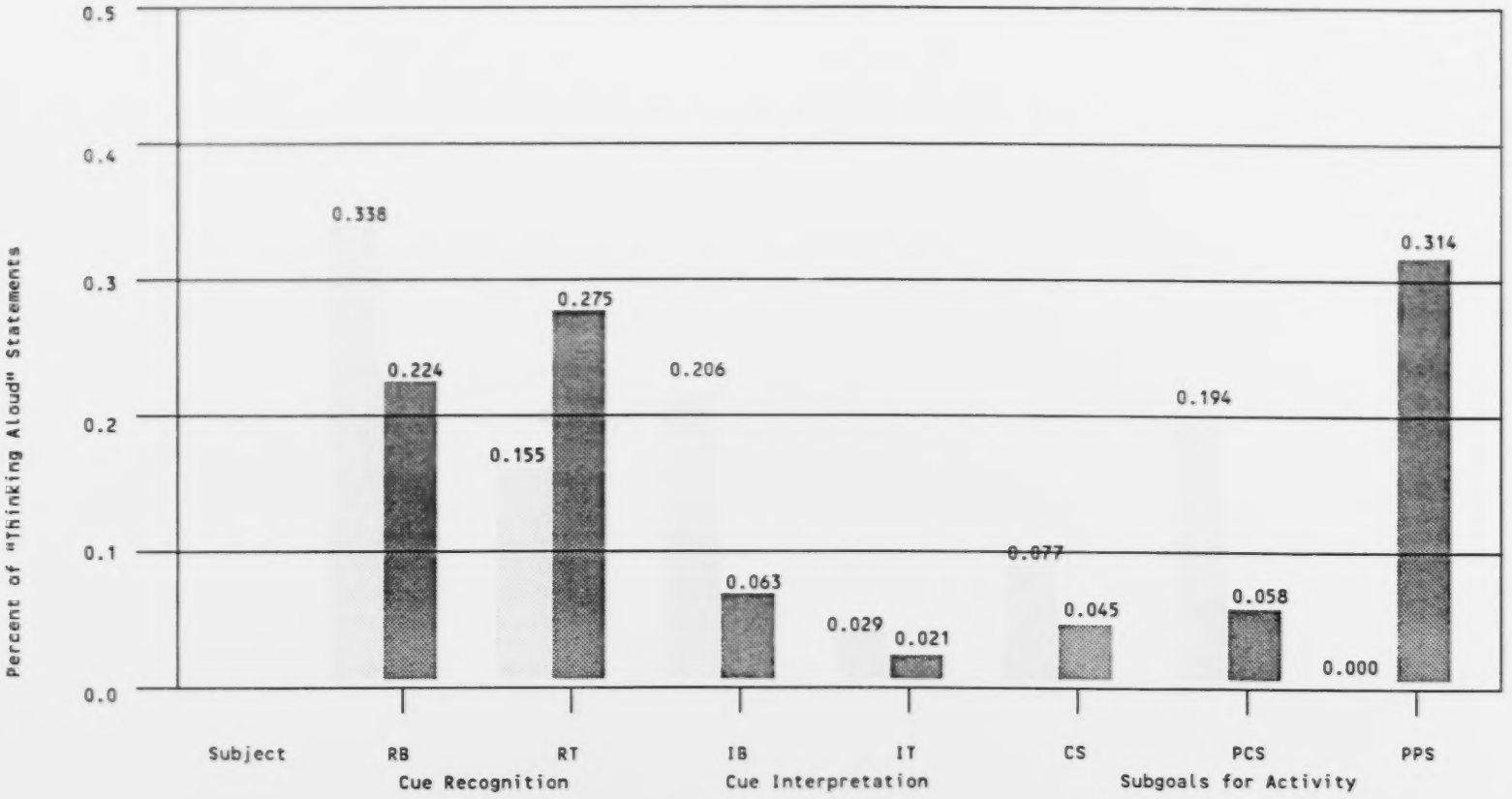
The results of the quantitative data analysis in regard to subjects' cue recognition, cue interpretation, and subgoals for problem solving task segments are presented in Figure 2.

Figure 1. Number of statements reflecting role as parent in pre-task interview by expert and novice parent groups.



Note. E = expert subject; N = novice subject

Figure 2. Components of knowledge structures and thought processes by expert and novice parent groups.



Note. E = expert subject; N = novice subject; RB = recognition of child behavioral cue; RT = recognition of toy or task/situation cue; IB = interpretation of child behavioral cue; IT = interpretation of toy or task/situation cue; CS = child subgoal; PCS = parent subgoal, child-focused; PPS = parent subgoal, parent-focused.

Regarding cue recognition the experts made a considerably higher percentage of statements reflecting recognition of behavioral cues given by their child than the novices. The novices made a higher percentage of statements reflecting recognition of cues related to the toy or task/situation than the experts. In the two code categories related to the cue interpretation, the experts made a higher percentage of statements in both categories than the novices.

Three of the code categories used to infer cognitive processes used by the subjects in the problem solving task related to subgoals operating during the task. Two of these categories were oriented toward the child, and one was parent-focused. The expert group made a higher percentage of statements reflecting subgoals than the novices in both of the child-oriented subgoal categories. The parent subgoal, parent-focused category consisted of statements made by the mother reflecting goals based on what would meet the mother's need in relation to her child or the situation. None of the experts made statements in this category, while 31.4 percent of the subgoal statements made by novices were in this category.

It is clear from the data presented in Figure 2 that the expert and novice groups differed considerably in their attentional focus leading to cue recognition, and cue interpretation, in the proportion of their statements that reflected cue interpretation, and in the attentional focus of their subgoals. The experts reflected much more attention during the activity to cues given by their child than to cues related to the toys or the task. Novices reflected more attention to cues related to the toys or the task than to cues given by their child. Experts expressed more overall cue interpretation, especially in relation to cues given by their child. Experts were much more strongly oriented than were the novices to their child's desires and needs than to their own needs during the task. All of the subgoal statements made by the expert group were focused on their child, and either reflected the mother's perception of the child's own subgoals in the situation or the mother's subgoals for the child based on what she saw as the child's needs. It is particularly dramatic that 31.4 percent of the novice subgoal statements were parent-need-focused with no apparent relation to a cue given by the child, whereas none of the subgoal statements made by the expert parents during the task were parent-need-focused. The child-focused nature of the experts' subgoals and the relatively high number of parent-focused novice subgoals is consistent with the data on overall task goals.

Reflections of Role as Parent

Novices' and experts' expressions of their roles as a parent in the stimulated recall interview differed considerably in

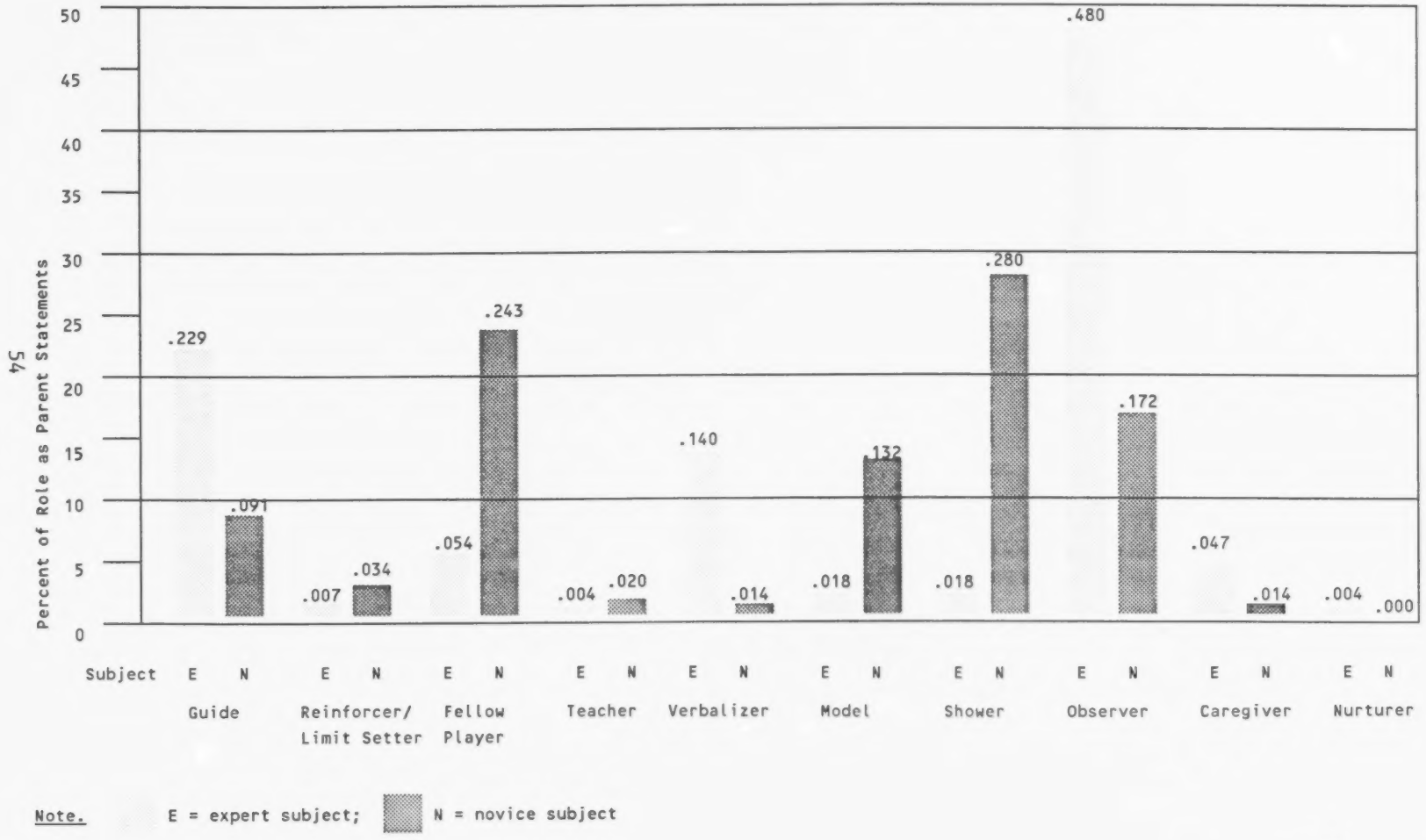
several role areas (see Figure 3). The parent role categories indicated most frequently by the expert parents were observer, guide, and verbalizer. The categories of parent role indicated most frequently by the novice group of parents were shower, fellow player, observer, and model. The role of observer was mentioned by both expert and novice parents. It was indicated in almost half of the statements about parent roles made by the expert group, this group having over 30 percent more observer role statements than the novice parents. The roles of observer, guide, and verbalizer noted more frequently in the statements of experts are roles in which the parent is usually less directive or intrusive in interaction with their child than in other roles, allowing the child to take the initiative in the situation. The roles of shower and fellow player which were frequently expressed by the novices can involve more directive and possibly intrusive parental action in parent-child interaction, and the parent is often the initiator of the action.

In comparing the role as parent data from the pre-task and stimulated recall interviews, the experts were consistent in frequently expressing the parent role of guide. The experts indicated a higher incidence of the observer role during the actual problem solving activity than they did during the pre-task interview. The only role expressed in ten percent or more of the novice parent statements during both the pre-task and stimulated recall interviews was the fellow player role. For both the experts and novices there was a greater range in the frequently mentioned parent roles during the pre-task interview than during stimulated recall. The novices, however, showed more inconsistency in the roles expressed than the experts in the two interviews.

Representation of Knowledge Content and Structure and Thought Processes

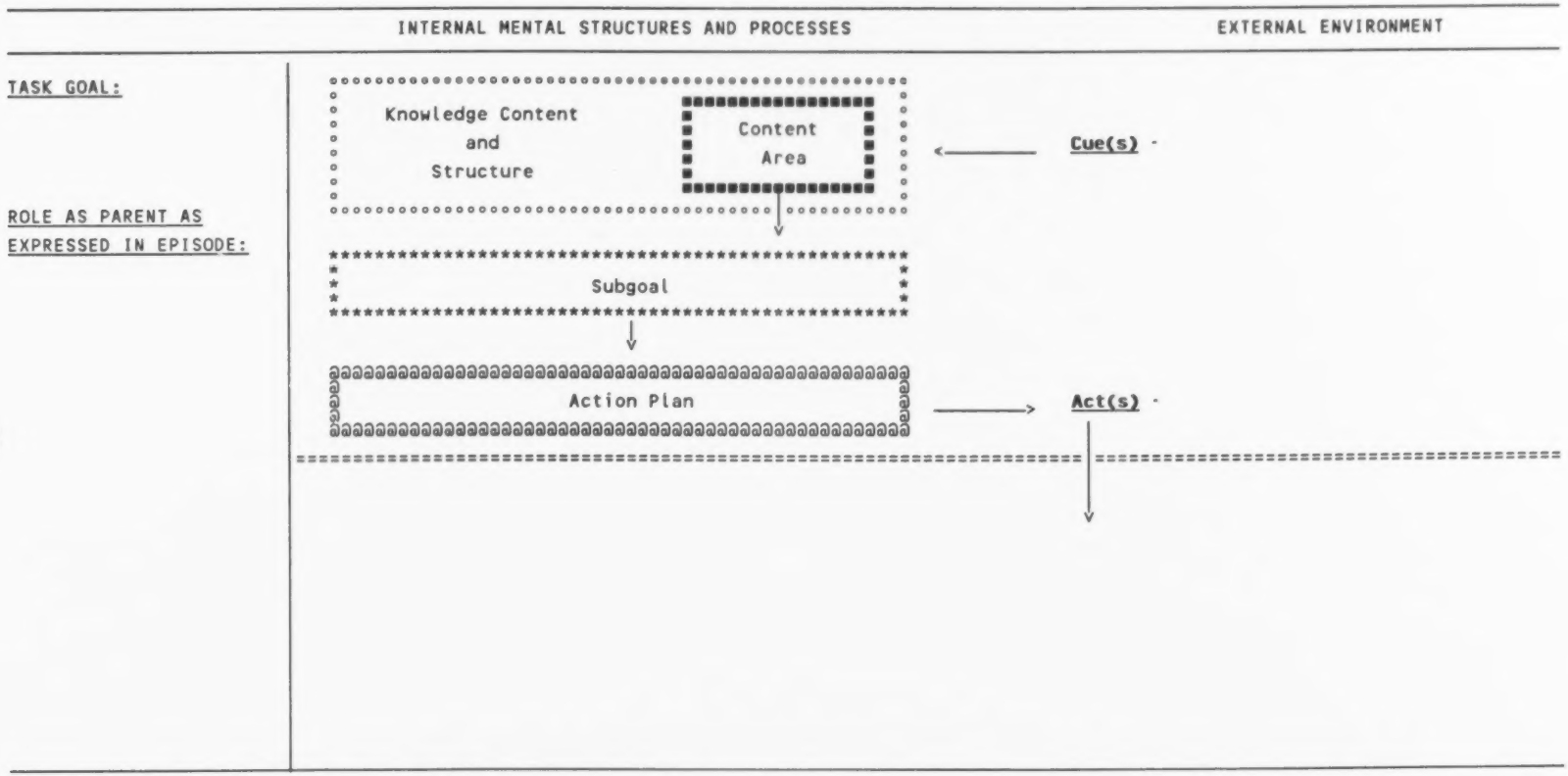
The data collected during and immediately after the problem solving situation were analyzed qualitatively in order to more clearly and completely represent the knowledge content and structure and thought processes of the subjects as they were involved in the problem solving task. Toy use episodes were selected from the subjects' verbal protocols for this analysis to illustrate and compare the external environment and the subjects' internal mental structures and processes. The format for representing these components is illustrated in Figure 4. The particular type of toy used in the episode is included in the figure title along with whether the parent was an expert or a novice. The far left column lists the overall task goal and the role(s) as parent expressed in the episode. The external environment is displayed on the right side of the figure and includes the cues and acts in each episode. The cues were the observable elements in the situation and the acts were the actions of the subject following, but not necessarily in response

Figure 3. Number of statements reflecting role as parent in stimulated recall interview by expert and novice parent groups.



Note. E = expert subject; N = novice subject

Figure 4. Knowledge structures and thought processes of expert or novice parent engaging infant's interest in use of a particular toy or play object.



Legend:
- ■■■■■■■■■■■■ = Content area
- °°°°°°°°°°°° = Entire knowledge content and structure
- ********** = Subgoal
- @@@@@@@@@@@ = Action plan
- ========== = Indicates end of segment within a toy use episode
- Arrows = Sequence of thought expression

to, these cues. The internal mental structures and processes are designated to the left of the cues and acts with rectangles having varied borders (see legend in Figure 4). Components of the internal mental structures and processes included: (a) the knowledge content reflected in the subject's statements made during thinking aloud or during stimulated recall, (b) the structure of this knowledge content, (c) the subgoals expressed by the subject in relation to the particular episode, and (d) the action plan expressed by the subject in relation to the conditions in the situation. The knowledge content and structure together with the subgoals for the situation and the action plans for responding to the situation, formed a condition-action unit. Arrows are used within the knowledge content and structure to connect statements made by a subject to a content area and to trace the sequence in which content areas were mentioned. Arrows also connect cues in the external environment to components of the internal mental structures and connect mental processes to acts in the external environment.

Examples of expert and novice knowledge structures and thought processes while engaging their infant's interest in use of metal kitchen objects are illustrated in Figures 5 and 6; Figures 7 and 8 illustrate examples while engaging infant's interest in use of a book. The data illustrated in these figures bring together into a more unified picture much of what was found in the other data analyses. A number of important differences between the experts and novices were clearly evident in these figures. The differences noted in all of the figures that were analyzed are described below, with examples of these differences evident in Figures 5-8 indicated.

1. The novices missed or misinterpreted move cues from their child compared to the experts who demonstrated more attention to and responsiveness to cues from their child. In Figure 6, for example, the novice parent interpreted her child's behavior of continuing to chew on a metal cup as evidence that he was bored and wanted her to give him something else to play with. The child was likely to have been getting sensory pleasure from chewing on the metal cup. This same novice parent also tried twice while the child was holding and chewing on the cup to move the cup and get the child to use it in a different way. In contrast, the expert mother in Figure 5 recognized her child's behavior with the metal kitchen objects as an indication of her child's liking them. This parent allowed the child to use the objects as the child chose while the parent observed and verbalized her child's behavior. This parent also modeled an alternative use of the metal objects after observing her child's behavior, and then again observed her child's response.

   Similar lack of attention to or misinterpretation of cues is evident in the novice behaviors during the book use

Figure 5. Knowledge structures and thought processes of expert parent engaging infant's interest in use of metal kitchen objects.

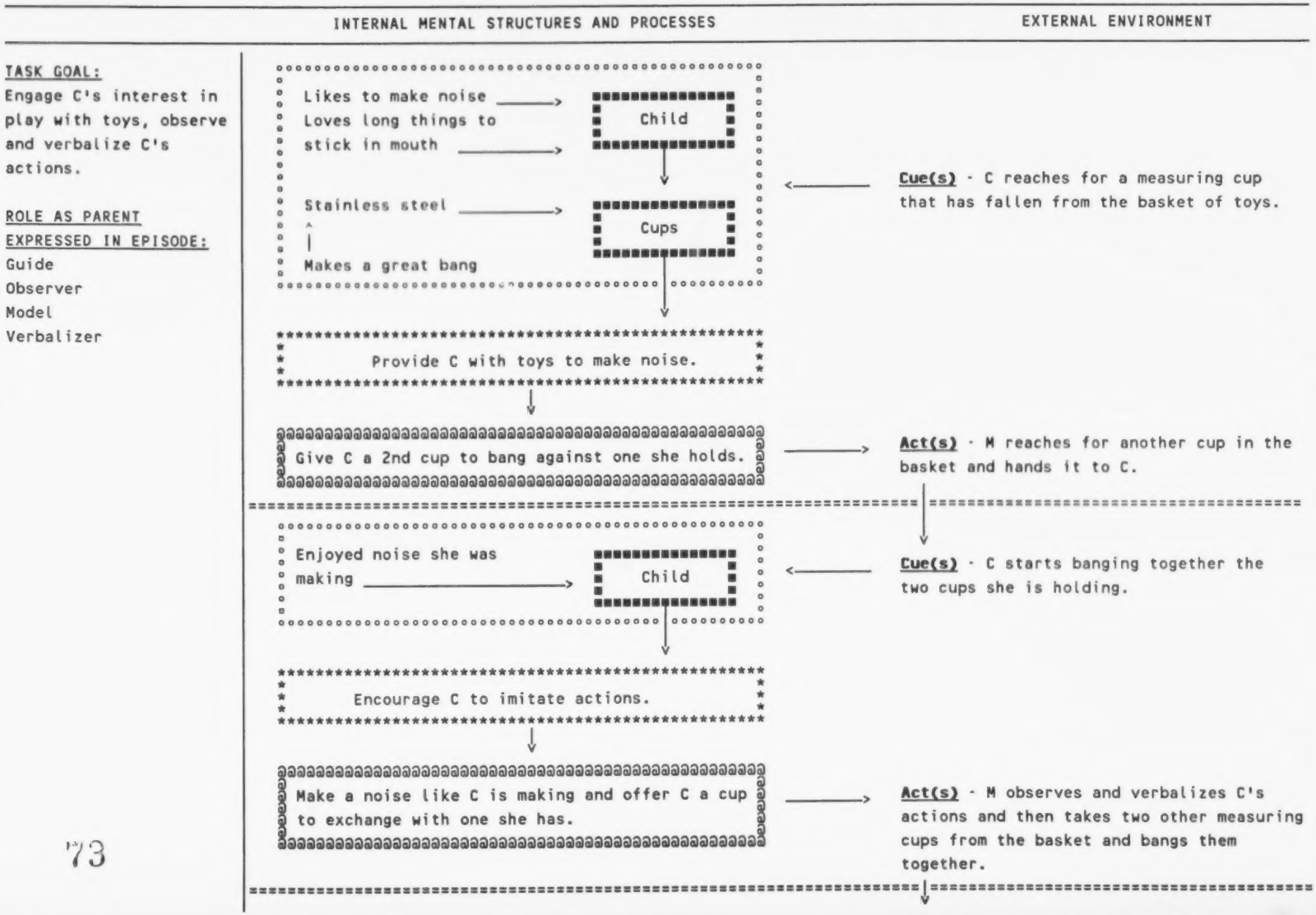

INTERNAL MENTAL STRUCTURES AND PROCESSES
EXTERNAL ENVIRONMENT
TASK GOAL:
Engage C's interest in play with toys, observe and verbalize C's actions.
ROLE AS PARENT EXPRESSED IN EPISODE:
Guide
Observer
Model
Verbalizer
Likes to make noise
Loves long things to stick in mouth
Child
Stainless steel
Makes a great bang
Cups
Cue(s) - C reaches for a measuring cup that has fallen from the basket of toys.
Provide C with toys to make noise.
Give C a 2nd cup to bang against one she holds.
Act(s) - M reaches for another cup in the basket and hands it to C.
Enjoyed noise she was making
Child
Cue(s) - C starts banging together the two cups she is holding.
Encourage C to imitate actions.
Make a noise like C is making and offer C a cup to exchange with one she has.
Act(s) - M observes and verbalizes C's actions and then takes two other measuring cups from the basket and bangs them together.

Figure 5. (Continued--2nd page)

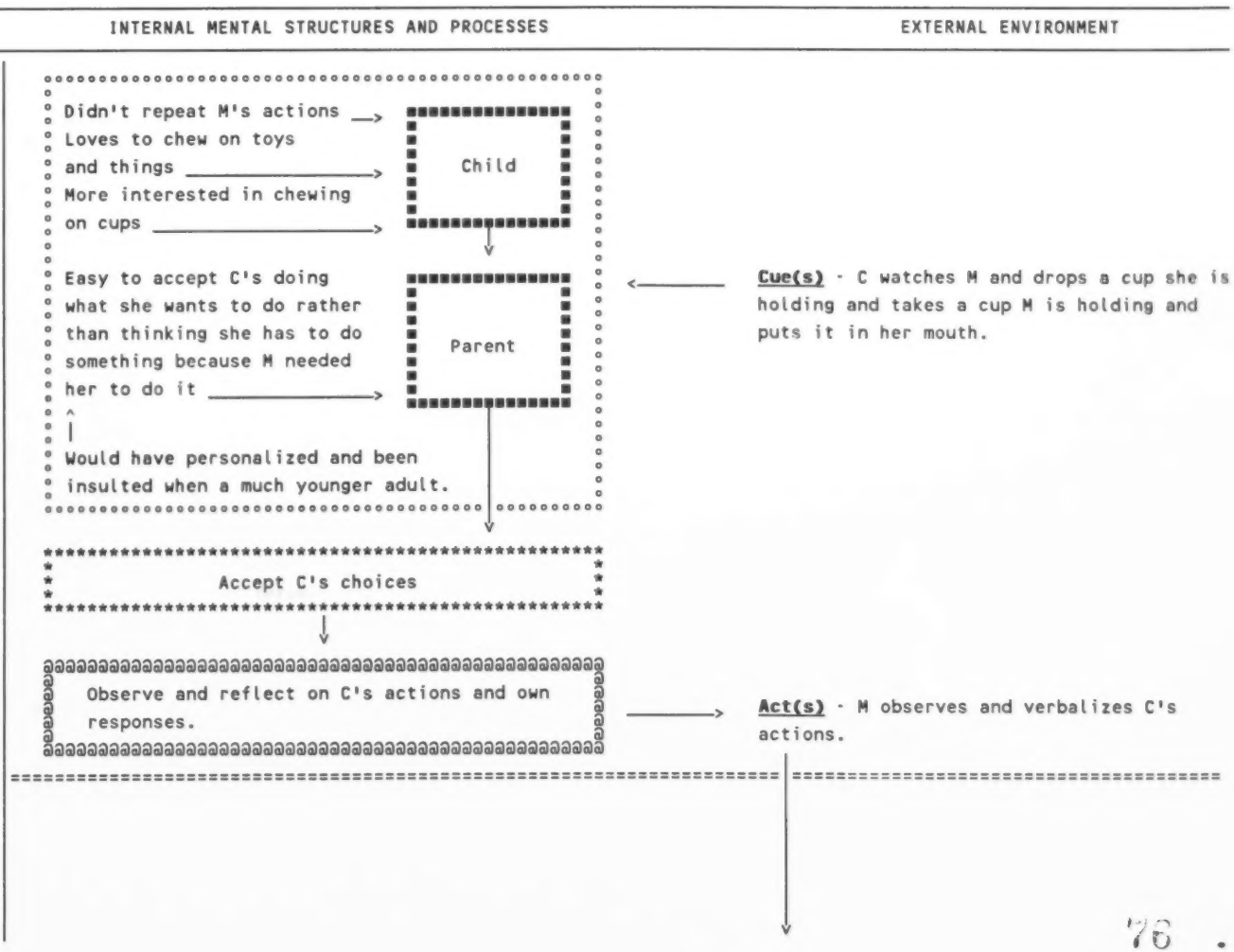

INTERNAL MENTAL STRUCTURES AND PROCESSES
EXTERNAL ENVIRONMENT
Didn't repeat M's actions
Loves to chew on toys
and things
More interested in chewing
on cups
Child
Easy to accept C's doing
what she wants to do rather
than thinking she has to do
something because M needed
her to do it
Would have personalized and been
insulted when a much younger adult.
Parent
Cue(s) - C watches M and drops a cup she is holding and takes a cup M is holding and puts it in her mouth.
Accept C's choices
Observe and reflect on C's actions and own responses.
Act(s) - M observes and verbalizes C's actions.

Figure 5. (Continued--3rd page)

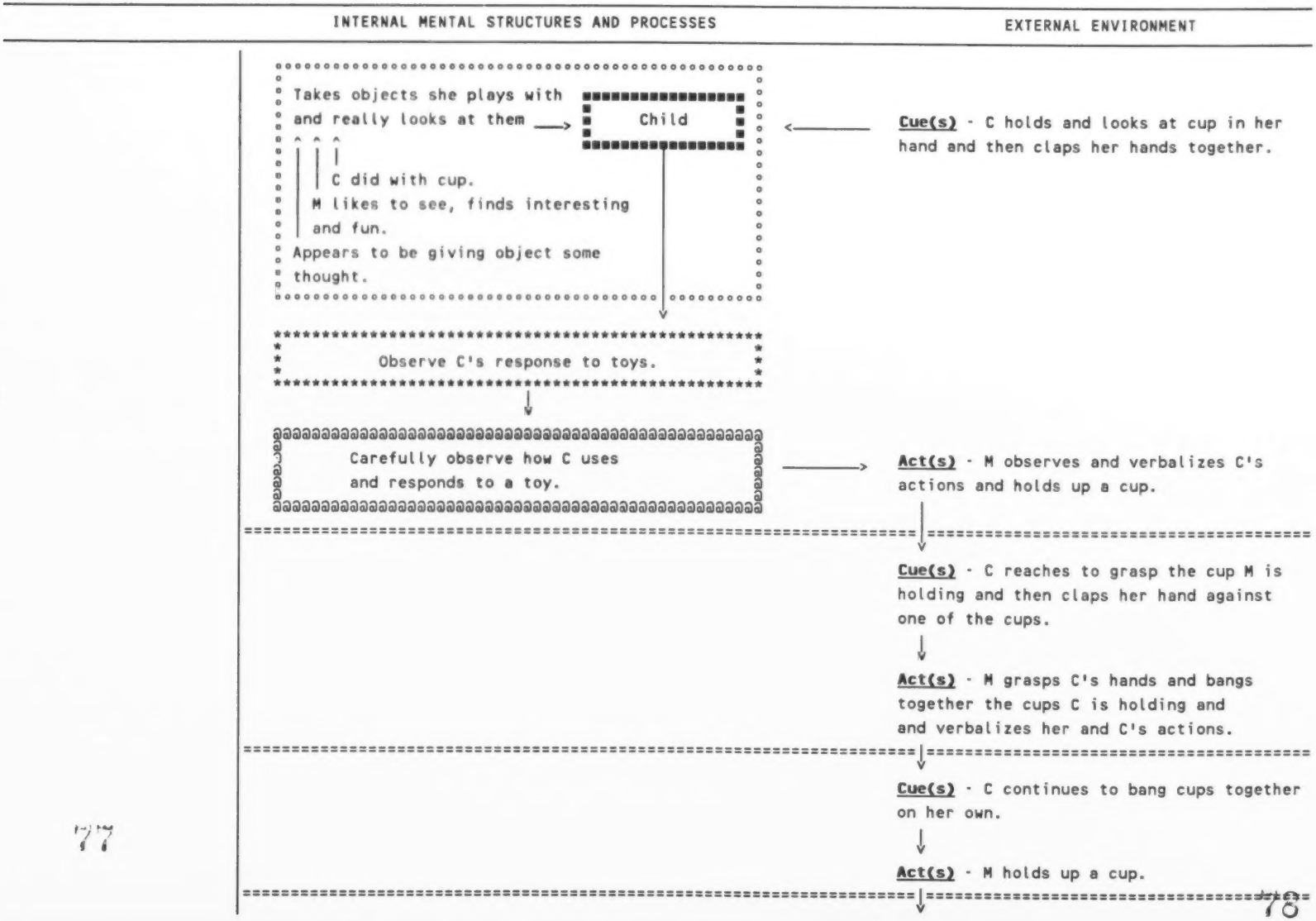

INTERNAL MENTAL STRUCTURES AND PROCESSES
EXTERNAL ENVIRONMENT
Takes objects she plays with and really looks at them
Child
C did with cup.
M likes to see, finds interesting and fun.
Appears to be giving object some thought.
Observe C's response to toys.
Carefully observe how C uses and responds to a toy.
Cue(s) - C holds and looks at cup in her hand and then claps her hands together.
Act(s) - M observes and verbalizes C's actions and holds up a cup.
Cue(s) - C reaches to grasp the cup M is holding and then claps her hand against one of the cups.
Act(s) - M grasps C's hands and bangs together the cups C is holding and and verbalizes her and C's actions.
Cue(s) - C continues to bang cups together on her own.
Act(s) - M holds up a cup.

Figure 5. (Continued--4th page)

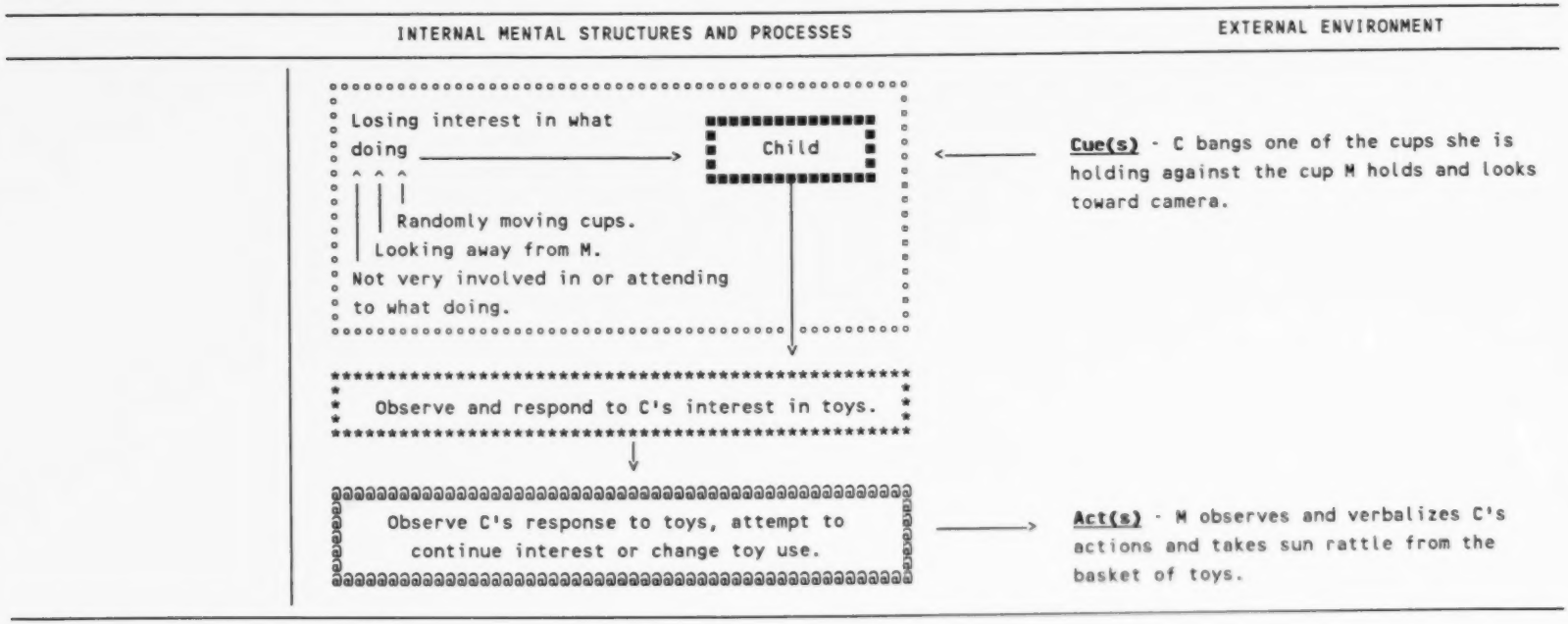

INTERNAL MENTAL STRUCTURES AND PROCESSES
EXTERNAL ENVIRONMENT
Losing interest in what doing
Child
Randomly moving cups.
Looking away from M.
Not very involved in or attending to what doing.
Observe and respond to C's interest in toys.
Observe C's response to toys, attempt to continue interest or change toy use.
Cue(s) - C bangs one of the cups she is holding against the cup M holds and looks toward camera.
Act(s) - M observes and verbalizes C's actions and takes sun rattle from the basket of toys.

Figure 6. Knowledge structures and thought processes of novice parent engaging infant's interest in use of metal kitchen objects.

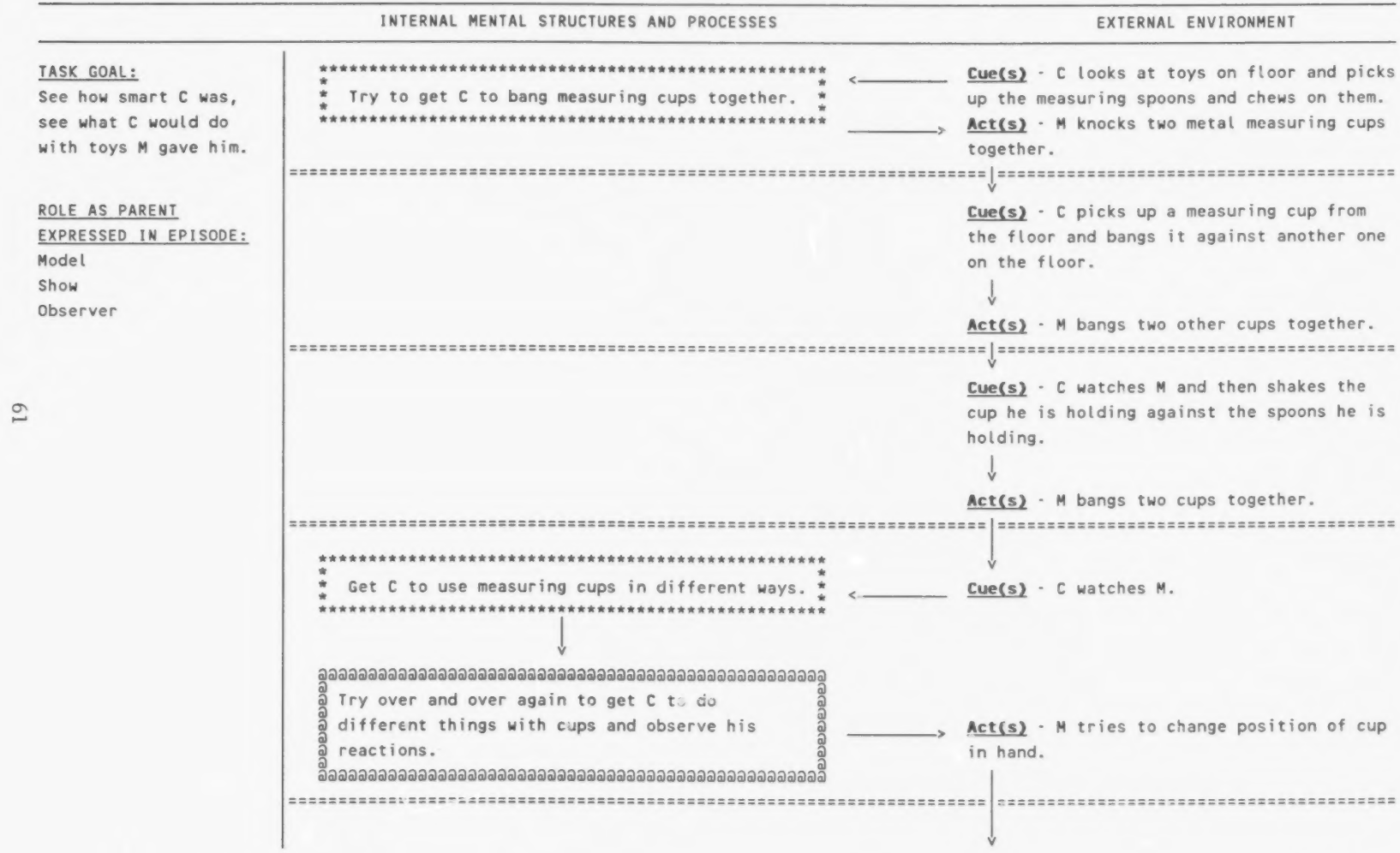

INTERNAL MENTAL STRUCTURES AND PROCESSES
EXTERNAL ENVIRONMENT
TASK GOAL:
See how smart C was, see what C would do with toys M gave him.
ROLE AS PARENT EXPRESSED IN EPISODE:
Model
Show
Observer
Try to get C to bang measuring cups together.
Cue(s) - C looks at toys on floor and picks up the measuring spoons and chews on them.
Act(s) - M knocks two metal measuring cups together.
Cue(s) - C picks up a measuring cup from the floor and bangs it against another one on the floor.
Act(s) - M bangs two other cups together.
Cue(s) - C watches M and then shakes the cup he is holding against the spoons he is holding.
Act(s) - M bangs two cups together.
Get C to use measuring cups in different ways.
Cue(s) - C watches M.
Try over and over again to get C to do different things with cups and observe his reactions.
Act(s) - M tries to change position of cup in hand.

Figure 6. (Continued--2nd page)

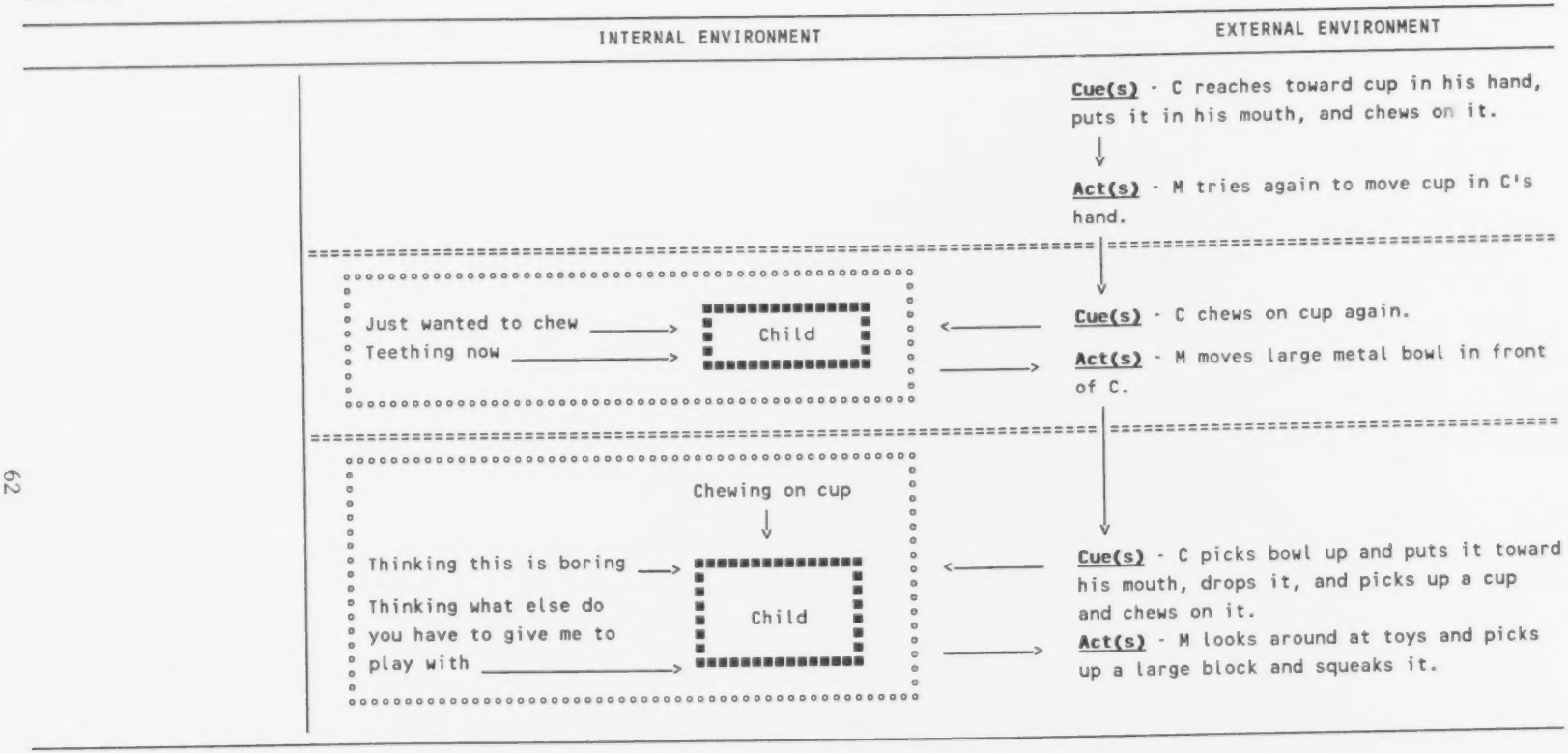

INTERNAL ENVIRONMENT
EXTERNAL ENVIRONMENT
Cue(s) - C reaches toward cup in his hand, puts it in his mouth, and chews on it.
Act(s) - M tries again to move cup in C's hand.
Just wanted to chew
Teething now
Child
Cue(s) - C chews on cup again.
Act(s) - M moves large metal bowl in front of C.
Chewing on cup
Thinking this is boring
Thinking what else do you have to give me to play with
Child
Cue(s) - C picks bowl up and puts it toward his mouth, drops it, and picks up a cup and chews on it.
Act(s) - M looks around at toys and picks up a large block and squeaks it.

Figure 7. Knowledge structures and thought processes of expert parent engaging infant's interest in use of book.

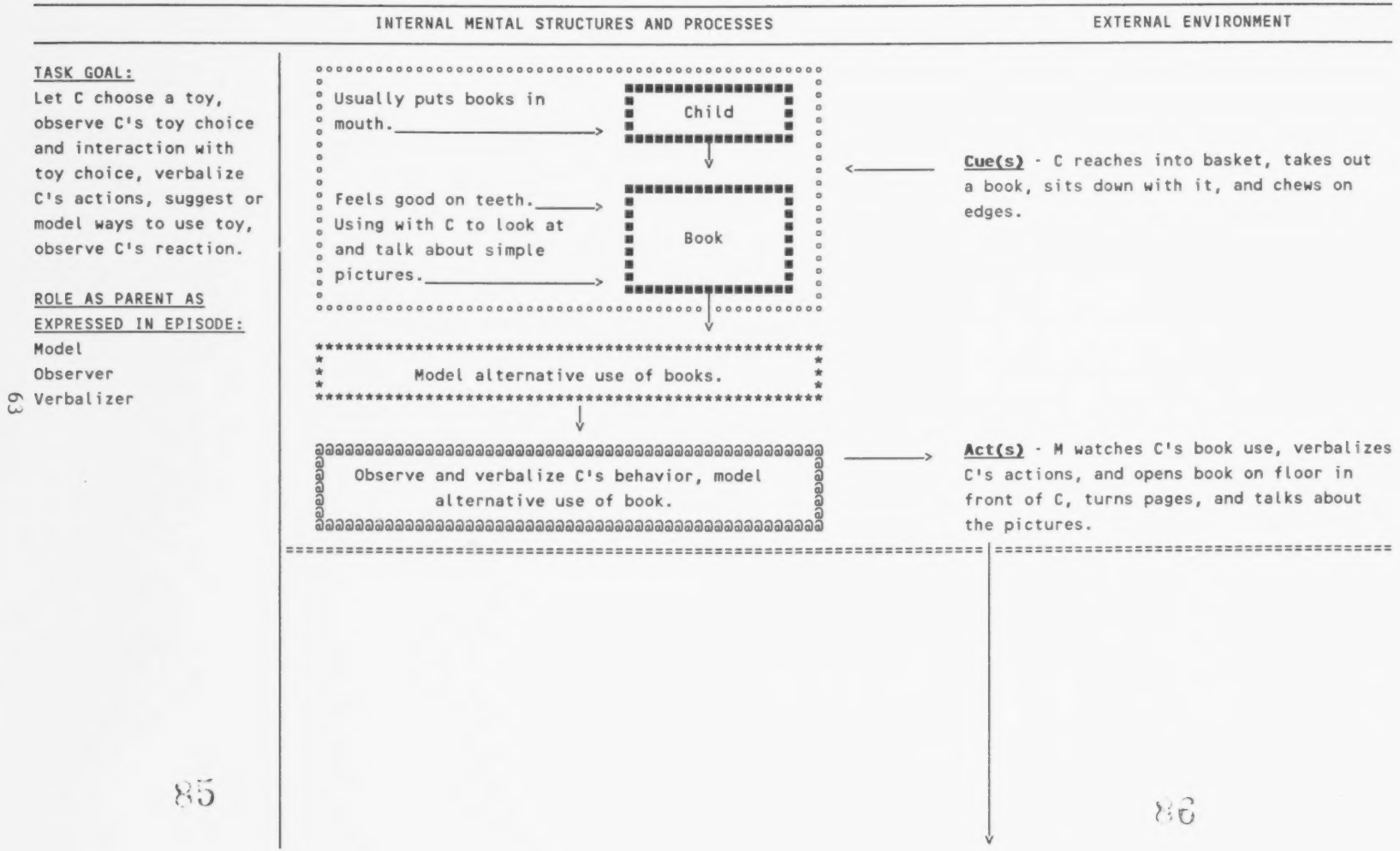

INTERNAL MENTAL STRUCTURES AND PROCESSES
EXTERNAL ENVIRONMENT
TASK GOAL:
Let C choose a toy, observe C's toy choice and interaction with toy choice, verbalize C's actions, suggest or model ways to use toy, observe C's reaction.
ROLE AS PARENT AS EXPRESSED IN EPISODE:
Model
Observer
Verbalizer
Usually puts books in mouth.
Child
Feels good on teeth.
Using with C to look at and talk about simple pictures.
Book
Cue(s) - C reaches into basket, takes out a book, sits down with it, and chews on edges.
Model alternative use of books.
Observe and verbalize C's behavior, model alternative use of book.
Act(s) - M watches C's book use, verbalizes C's actions, and opens book on floor in front of C, turns pages, and talks about the pictures.

Figure 7. (Continued--2nd page)

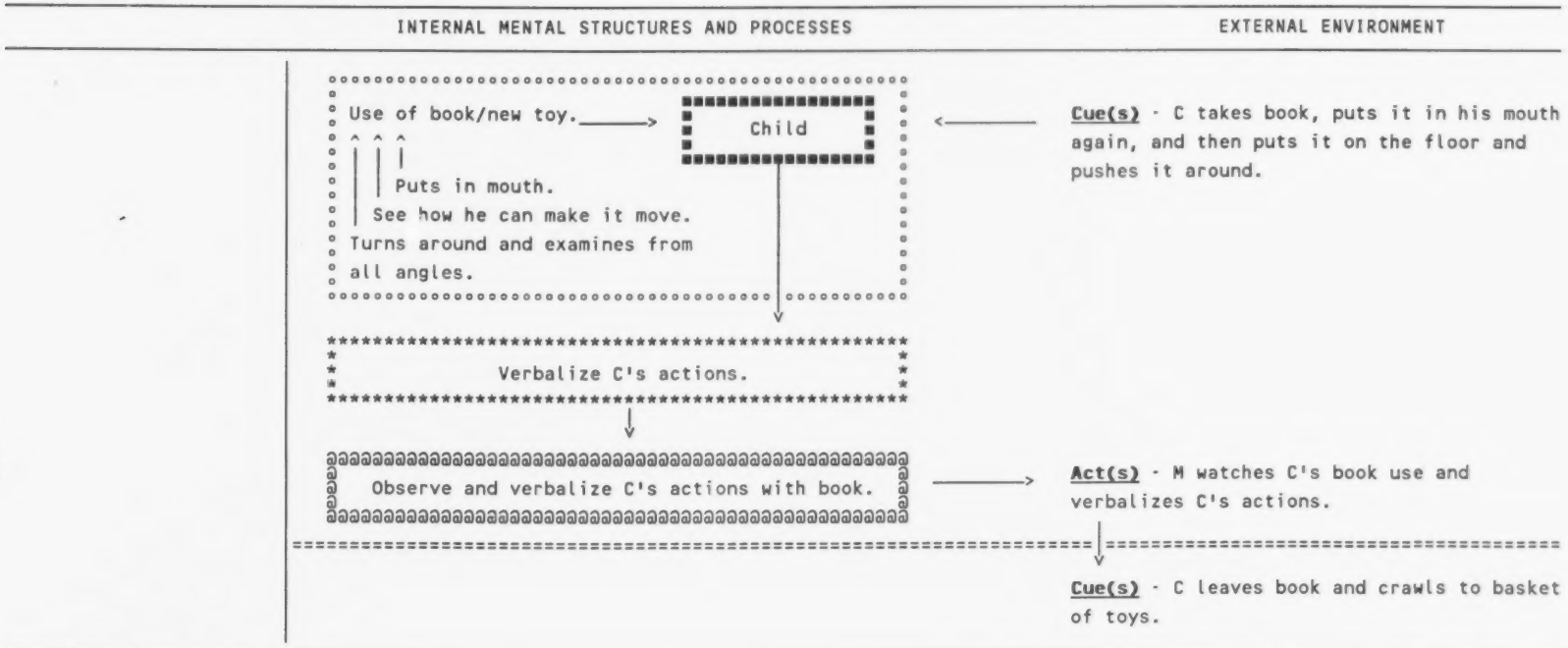

INTERNAL MENTAL STRUCTURES AND PROCESSES
EXTERNAL ENVIRONMENT
Use of book/new toy.
Child
Puts in mouth.
See how he can make it move.
Turns around and examines from all angles.
Verbalize C's actions.
Observe and verbalize C's actions with book.
Cue(s) - C takes book, puts it in his mouth again, and then puts it on the floor and pushes it around.
Act(s) - M watches C's book use and verbalizes C's actions.
Cue(s) - C leaves book and crawls to basket of toys.

Figure 8. Knowledge structures and thought processes of novice parent engaging infant's interest in use of book.

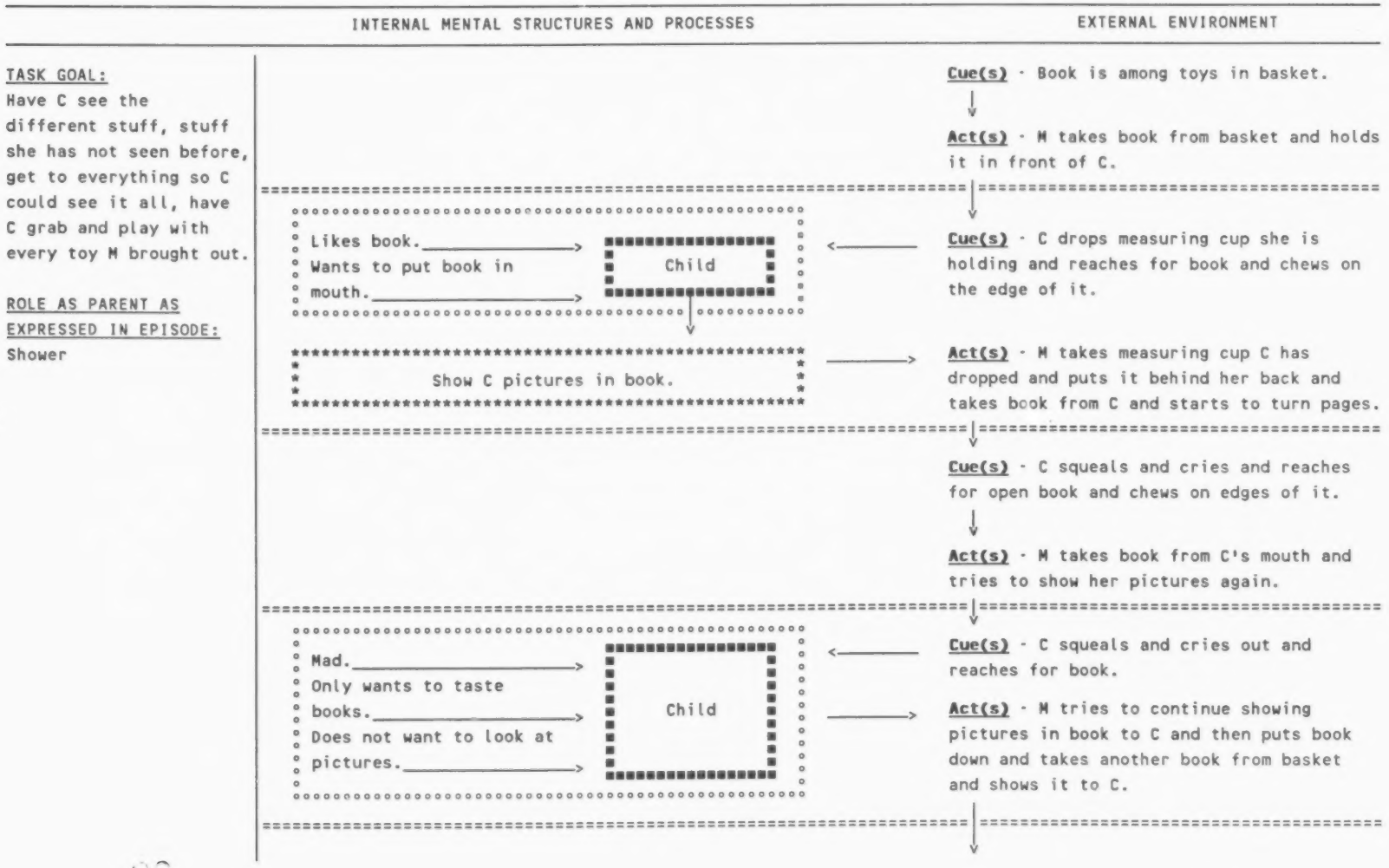
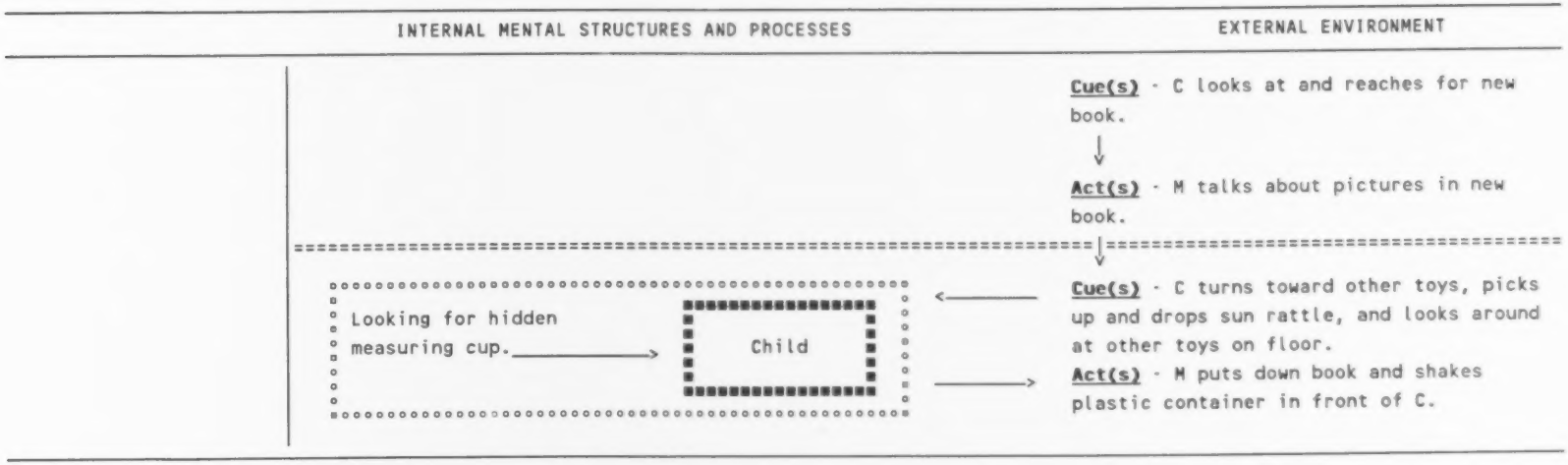

INTERNAL MENTAL STRUCTURES AND PROCESSES
EXTERNAL ENVIRONMENT
TASK GOAL:
Have C see the different stuff, stuff she has not seen before, get to everything so C could see it all, have C grab and play with every toy M brought out.
ROLE AS PARENT AS EXPRESSED IN EPISODE:
Shower
Cue(s) - Book is among toys in basket.
Act(s) - M takes book from basket and holds it in front of C.
Likes book.
Wants to put book in mouth.
Child
Cue(s) - C drops measuring cup she is holding and reaches for book and chews on the edge of it.
Show C pictures in book.
Act(s) - M takes measuring cup C has dropped and puts it behind her back and takes book from C and starts to turn pages.
Cue(s) - C squeals and cries and reaches for open book and chews on edges of it.
Act(s) - M takes book from C's mouth and tries to show her pictures again.
Mad.
Only wants to taste books.
Does not want to look at pictures.
Child
Cue(s) - C squeals and cries out and reaches for book.
Act(s) - M tries to continue showing pictures in book to C and then puts book down and takes another book from basket and shows it to C.

Figure 8. (Continued--2nd page)


INTERNAL MENTAL STRUCTURES AND PROCESSES
EXTERNAL ENVIRONMENT
Cue(s) - C looks at and reaches for new book.
Act(s) - M talks about pictures in new book.
Looking for hidden measuring cup.
Child
Cue(s) - C turns toward other toys, picks up and drops sun rattle, and looks around at other toys on floor.
Act(s) - M puts down book and shakes plastic container in front of C.

episode. In Figure 8 it is quite clear that the child wanted to hold the book herself and manipulate and chew on its edges. The child squealed and cried when the novice mother took the book from her and persisted in trying to show the child the pictures in the book. In stark contrast, the expert parent represented in Figure 8 stated her child usually put books in his mouth and that when the child took a book from the basket of toys and began to chew on its edges it probably felt good on his teeth. This expert mother allowed her child to explore the book in his own way and observed and verbalized his actions before she opened the book he was using and talked about the pictures. When her child again took the book and again placed it in his mouth, she returned to observing and verbalizing his actions while he used the book as he chose.

The novices were often the ones who selected toys for their child rather than letting their child choose a toy in the toy use examples. Experts almost always let their child choose the toys. At the end of the toy use episode represented in Figure 6, it was the novice mother who selected a different toy for her child to play with even though he gave no indication that he wanted to have a different toy. In Figure 8, the novice parent selected a book from the basket of toys to show her child without any cues from the child that a switch in toy use was desired.

2. <u>The knowledge structures of the expert parents were clearly more complex and contained a considerably larger amount of content than the knowledge structures of the novices, and the content was also more accurate</u>. In all of the toy use episodes the experts showed much more complex knowledge structures and extensive content than the novices. For example, in the expert example of use of metal kitchen objects in Figure 5, the parent expressed extensive knowledge of her child, both knowledge of her child's response to the immediate situation and more general knowledge of her child stored in long-term memory that was relevant to interpreting the immediate situation. This expert also reflected knowledge content related to the play objects and to her own responses to her child's behavior in the situation. This parent was aware that it was easy for her to accept the child's doing what the child wanted to do rather than thinking the child had to do something because the mother needed the child to do it. This expert went on to state that when she was a much younger adult she would have personalized her child's lack of response to her parental suggestion and been insulted. This expert's knowledge of her own responses to her child's actions can be viewed as demonstration of the self-awareness and metacognitive skills of the parent, i.e., her ability to plan, direct, monitor, and control her own actions. These skills have been found to be associated with expertise in problem solving.

An examination of the knowledge reflected in the novice parent example of metal kitchen object use in Figure 6 clearly illustrates the sketchiness of the novices' knowledge during these episodes. This novice parent made only very brief references to knowledge of her child's responses in the immediate situation. As stated before, this parent perceived that her child was experiencing boredom in chewing on the cup and wanted her to give him something else to play with, a likely inaccurate interpretation of her child's actions at the moment. Similar patterns of minimal knowledge content and simple knowledge structure is evident in the other novice parent examples studied. In all cases the knowledge expressed by the novices was limited to the immediate situation with little or no evidence of knowledge stored in long-term memory.

What is particularly evident in the knowledge of the expert parents is the extent to which they expressed and responded to their child based on stored knowledge of typical behavior patterns of their child. This knowledge of typical behavioral patterns seemed to be triggered by only one or a few simple cues from their child. Examples of this process of pattern recognition in the thinking of the expert parents is illustrated in Figures 5 and 7. The parent represented in Figure 5 noticed her child holding and looking at a cup. The parent responded by describing how her child typically took the objects she played with and really looked at them and appeared to be giving the objects some thought. The parent represented in Figure 7 described her child's typical use of a new toy in relation to his putting the book in his mouth and then putting it on the floor and pushing it around. The parent in this situation stated that her child used a new toy by putting it in his mouth, turning it around and examining it from all angles, and seeing how he could make it move.

Almost all of the expert and novice parents expressed specific knowledge of their child. As already indicated, the novices reflected knowledge of their child only in relation to their child's behavior in the immediate situation. In contrast, the experts expressed more general knowledge of their child that was stored in long-term memory and activated by cues in their child's behavior in the immediate situation. In some instances the knowledge expressed by the expert parents indicated integration of knowledge from the domain of child development.

As already indicated in relation to Figure 6, novices appeared to make inaccurate assumptions about what they thought their child was thinking or feeling. There was also evidence indicating that novice parents had inaccurate information about how children learn and develop.

3. The subgoals expressed by the expert parents in the toy use episodes were all child-focused whereas each novice parent reflected at least one instance in which their subgoal was focused more on their own parental desires for what they wanted their child to do and did not reflect attention to cues given by their child. The novice parent in Figure 6 stated that she wanted to get her child to use the measuring cups in different ways. She tried twice to move the cups in her child's hands the way she wanted him to move them despite cues given by the child that he wanted to chew on the cups. A similar situation was noted in the novice parent book use episode represented in Figure 8. This novice mother wanted to show her child the pictures in the book while the child was giving cues indicating a desire to hold the book herself and chew on its edges.

   The expert parent examples included many more indications of subgoals than the novice examples. All of the experts' subgoals were child-focused. The experts represented in Figures 5 and 7, encouraged but did not require the child to imitate actions, verbalized the child's actions, modeled alternative toy uses, and observed and responded to the child's interests. The experts stated subgoals likely to provide opportunities for their child to take the initiative in the problem solving situation, whereas the novices were much more likely to miss or limit their child's opportunities to take the initiative because the novice parents' subgoals focused more on their own needs for their child to act in a particular way in the situation.

4. The experts stated a plan for action in almost every segment of the expert toy use episode examples. These action plans all demonstrated attention to the child's needs in the situation. The most action plans stated by a novice in a toy use episode example were two, and those plans were not consistently child-focused. No action plans were expressed by the novice parent represented in Figure 8. The one action plan expressed by the novice parent in Figure 6 illustrated a plan in which she chose to persist in actions to try to meet her subgoal without recognizing the cues given by her infant. Examples of the many child-focused action plans expressed by the experts are found in Figures 5 and 7 and include: (a) observe and reflect on child's actions, (b) model alternative use of book, and (c) verbalize child's actions.

5. The overall parental roles expressed in toy use episodes by both the expert and novice parents were consistent with their stated subgoals and action plans. Because their subgoals and action plans differed, however, parental roles expressed in these episodes differed between the expert and novice examples. All of the expert examples included parental roles of observer, verbalizer, and model. The guide role was also

frequently mentioned by the experts. The role most frequently indicated by novices was the role of shower. Novices also frequently mentioned the roles of model and fellow player. The differences in the parent roles expressed by expert and novice parents in these examples is especially clear when the same type of toy use episode is contrasted for expert and novice subjects. For example, the novice parent in the book use episode in Figure 8 expressed her role solely as one of shower. The expert example of book use represented in Figure 7 indicated the roles of observer, verbalizer and model.

6. The nature of the overall task goal for the episodes differed between expert and novice groups. These differences were consistent with differences in the perceived external environment and internal mental structures and processes reflected by expert and novice parents. The novice task goals expressed in Figures 6 and 8 were clearly parent-focused, i.e., seeing how smart the child was, seeing what the child would do with the toys the mother gave him, and getting the child to everything so the child could see it all. Consistent with other expert parent data, the overall task goals expressed by the expert parents in Figures 5 and 7 were child-focused and included engaging the child's interest in play with the toys, observing and verbalizing the child's actions, letting the child choose a toy, observing the child's toy choice and interaction with the toy, and suggesting or modeling ways to use the toy chosen by the child.

7. In almost all of the segments within each expert parent episode a complete condition-action unit was reflected in the internal mental structures and processes of the parent. This condition-action unit connected the cues in the external environment to the parent's acts in the external environment. The verbal data in all of the novice examples included only four complete condition-action units. Most of the segments within the novice episodes contained incomplete condition-action units. These incomplete units contained only knowledge, only subgoals or action plans, or combinations of knowledge and subgoals or subgoals and action plans. This pattern is evident in the novice examples in Figures 6 and 8. Half of the segments within these novice examples contained no internal knowledge content or structures or mental processes. In these cases, the cues and acts in the external environment may be compared to operating like a simple stimulus-response chain. These differences in the internal knowledge content and structures and mental processes further illustrate the differences in the content and complexity of the thought of the expert and novice subjects during the problem solving task.

Research Methodology

It was one of the intents of the study to design and test research methodology for studying the cognitive aspects of everyday, ill-defined human problem situations. The two methodological approaches that were adapted and tested in this study were "thinking aloud" and stimulated recall interview procedures for collecting verbal protocols. These methods worked well for their intended purposes. The combined use of these two methods, versus using only one of the methods, made it more likely that the verbal protocols collected were a thorough and accurate representation of the thinking of the subject during the problem solving task and captured the knowledge structures and thinking processes of the subjects. The videotaping of the subjects and their infants in their homes did not prove to be as intrusive and disruptive as was expected. The subjects appeared to be self-conscious at the beginning of the activity more because of the request to "think aloud" during the task since this was a skill with which they were not familiar than because they were being videotaped. It was more familiar and comfortable for the subjects to express their thoughts aloud through talking to their infants during the task since this they typically did. Both the expert and novice subjects were more likely to fall into this pattern of talking than to state their thoughts out loud in strict "thinking aloud" format.

The actual task selected for the problem solving activity was a task that worked well in eliciting knowledge structures and mental processes. The criteria used for expert and novice parent subject selection also worked well for this research problem.

Conclusions, Implications, and Recommendations

Conclusions

Attentional Focus

Recognition of the cues given by the infants during the problem solving activity required the attentional focus of the parents on their child. The expert parents demonstrated over twice as much attentional focus on the behavioral cues given by their child during the task as the novice parents. The novice parents showed more attention to cues related to the toys or task/situation than to behavioral cues provided by their infant. The novices were much more likely than the experts to miss behavioral cues given by their child and acted in ways that appeared to be directed toward meeting their own needs and goals in the situation in spite of repeated cues from their child that the child had different goals and interests.

The data support the conclusion that attentional focus on cues from their child is critical to parental responsiveness to these cues.

Cue Interpretation and Knowledge Content and Structures

Accurate cue interpretation has an important influence on the effectiveness of parental actions. Cue interpretation occurs when cues are recognized and then related to stored information in memory. The novices did very little cue interpretation compared to the experts, especially in interpreting cues provided by their child. The ability of the experts to interpret cues was likely facilitated by the extent of knowledge the experts had about their child and about the domain of child development. The experts not only had more specific knowledge of their child than the novices, they had more knowledge in the domain of child development which appeared to influence the accuracy of their specific knowledge of their child and, consequently, the amount and accuracy of their cue interpretation.

Not only did the novices have less knowledge of their child than the experts, but the knowledge they had reflected mostly surface aspects of their child's behavior in the immediate situation. The experts expressed both specific knowledge of their child's actions in the immediate situation and specific knowledge of their child that included more complex knowledge of patterns of behavior that were typical of their child. The experts were able to match cues in their child's behavior to these behavioral patterns stored in long-term memory. This stored knowledge of behavioral patterns indicated the greater complexity evident in the knowledge structures, or schemas, of the experts.

The data support the conclusion that the experts' ability and accuracy in cue interpretation leading to appropriate parental action was facilitated by the integration of specific knowledge of their child and domain knowledge related to child development.

Goals and Subgoals and Plans for Action

The goals of the expert parents for the outcome of the problem solving activity were focused on their perception of the needs and interests of their child and reflected recognition and interpretation of cues provided by their child. The goals of the novice parents for the task were much more focused on their own needs and interests and did not necessarily reflect recognition and interpretation of cues provided by their child. The subgoals for the task indicated by both the novice and expert parents were consistent with their choice of overall goals for the outcome of the situation.

Expert parents usually indicated thinking about a subgoal and plan for action for each portion of the problem solving task that reflected cues they recognized and interpreted. The action plans of experts were child-focused and appeared to be based on their subgoal in the particular episode of the situation. Subgoals and action plans were infrequently expressed by the novices, and when they were, they often focused more on parent-centered subgoals and plans for the situation than child-centered subgoals and plans.

The goals, subgoals, and action plans of the experts indicated a pattern of allowing their child to have a major share of the control in the situation. The novices' subgoals and action plans showed a much stronger need to control the situation. The novice parents' greater need to control the situation may have reflected their lack of knowledge and understanding of developmentally appropriate expectations for their child, of the competence of their child, and of the developmental value of supporting even very young children in becoming self-directive.

The data support the conclusion that the expert parents formulated child-centered goals, subgoals, and plans of action based on cue recognition and interpretation and stored knowledge of the child. These goals, subgoals, and plans for action led to expert behaviors which provided their child with opportunities, allowing the child a high degree of control in the situation and the opportunity for self-direction.

Beliefs and Actions in Relation to the Parent Role

The goals and expectations expressed by expert parents for their children were child-centered and reflected their knowledge of children and how they develop and their concern for providing for the developmental needs of their child. The more parent-focused goals and expectations of the novice parents for their child represented a more limited understanding of children and what is important to children's development. The novices also reflected hopes for meeting their own desires and needs through their child's accomplishments.

In expressing ideas about their role as a parent, the experts indicated a different type of pattern in parent role choices than the novices, especially as expressed in relation to the problem solving task. The experts indicated parent roles during the task which involved less directive and intrusive interaction with their child (the roles of observer, guide, and verbalizer) than the roles indicated by the novices (shower and fellow player). These differences in parent role choices were consistent with the goals, subgoals, and action plans of expert and novice parents and directly reflect differences in need for

control in problem solving situations with children. The experts also indicated their ability to reflect on their own role behavior, analyzing it, and selecting roles for action most appropriate for meeting the needs of their child. The novices gave no indication of doing this.

The data support the conclusion that experts focused on the developmental needs of their child in their goals and expectations for their child and in their parent role choices. The experts also indicated acting in parent roles in which they were likely to be less directive and intrusive in their interactions with their child than did the novices. The experts also expressed more reflective behavior than the novices in relation to their own parent role behaviors.

Knowledge Structures and Processing

Parental knowledge of their child, children in general, and their parental role appeared to be structured in the thoughts of the expert parents in the form of condition-action units. These units operated in the parents' thinking between recognition of a cue provided by their child and their actions in response to the cues. The condition portion of the unit included: (a) knowledge taken from the immediate situation and the activation of knowledge related to the situation stored in long-term memory and (b) subgoals of the parent for the situation. The action portion of the unit consisted of the action plan expressed by the parent as appropriate for the conditions. Cue interpretation occurred through bringing into attentional focus perceived aspects of the immediate situation and knowledge activated from long-term memory. This knowledge was processed in a way that made it useful in determining a subgoal and action plan for the situation that would lead to effective parental action. Expert parents consistently expressed thought reflecting knowledge structures in the form of condition-action units linking cue recognition to action. Novice parents expressed only parts or none of these components of a condition-action unit in much of their thinking related to the task.

The data support the conclusion that the expert parents processed knowledge available to them during the problem solving task through structures involving condition-action units before acting in response to cues from their child.

Expertise

The conclusions already discussed delineate the differences found between expert and novice parents engaged in a problem solving situation involving their infants. There were very clear differences in the manner in which expert and novice parents responded to the problem solving activity in relation to all of the study variables. Based on study results, it can be inferred

that the expert parents held complex stores of integrated declarative and procedural and specific and domain knowledge to which they had rapid access for use in cue interpretation and planning prior to problem representation and solution. The experts thought about goals, subgoals, and plans for action prior to acting in the situation. The experts appeared to be more automatic and efficient in their attentional focus and processing of information than the novices, and they knew what features in the situation were likely to be more informative than others in representing and solving the problem.

The data support the conclusion that the actions of the expert parents were appropriate, effective, and in direct response to the cues given by their child in the situation. The data also support the conclusion that the experts demonstrated automaticity and efficiency in focusing their attention on their child, elaborate and accurate knowledge content structured in complex formats, and reflective thinking prior to acting in the situation.

Research Methodology

The methodology developed and adapted for use in studying the everyday, ill-defined parental problem of engaging an infant's interest worked well for eliciting data needed to address the study objectives. The use of both "thinking aloud" and stimulated recall procedures for collecting verbal protocols strengthened the likelihood that this data was a thorough and accurate representation of the thoughts of the subjects during the problem. While the protocols obtained from each use of these two data collection procedures provided an incomplete account of the knowledge and thought processes operating for subjects as they solved the problem, the use of both concurrent and retrospective verbal reports yielded more comprehensive data for making reasonable inferences. The data collected from the subjects during the pre-task interview prior to involvement in the problem solving activity provided further useful verbal evidence to compare to subjects' statements during the problem solving activity. The challenge remains to find ways to even more effectively elicit the thinking of subjects during a problem solving activity, especially one involving interpersonal interaction. The criteria for expertise as effective subject selection criteria were reinforced by the consistency of the findings with the literature on novice-expert differences.

The data support the conclusion that the research methodologies used in the study for obtaining the verbal protocols of expert and novice subjects provided sufficient and appropriate data for use in inferring the knowledge content and structures and thought processes of the subjects during the problem solving activity.

Implications and Recommendations

For Educational Practice

The results of this study indicate that there were very clear differences in the thought processes and knowledge structures of the expert and novice parents as they acted to solve problems with their infants. The knowledge discovered through this study contributes a piece of information in answer to the largely unanswered question of "What makes an effective, competent parent or caregiver?" What has been learned in answer to this question has implications for educational practice in parent education as well as for any educational practice where educators are helping individuals develop skills for dealing with everyday, ill-defined human interaction problems.

This study has shown that expertise in parenting in problem solving situations involving infants includes the following attributes: (a) attentional focus on cues relevant to the child's goals and needs in the problem solving situation, (b) extensive specific knowledge of the child's behavioral characteristics and a strong foundation of domain knowledge related to child development and child rearing which is integrated into the specific knowledge of the child, and (c) consciously considered child-focused goals and subgoals and plans for action which reflect thought about parental roles appropriate for the situation and response to cues from the child. As a result of using these mental processes and such knowledge, the expert parents were found to act to provide opportunities for their child to be self-directive.

At least three areas having implications for educational practice are evident in the study results. Each of these areas are described below and accompanied by recommendations for instruction in problem solving which are consistent with those discussed by Frederiksen (1984) and Thomas and Litowitz (1986).

First, it is evident that helping parents develop the ability to focus their attention on cues from their child is an important educational goal. Since most of the cues attended to by the parents were visual and often enhanced by audio cues from the child, educational activities and materials which help parents learn to focus on informative visual and audio cues in their child's behavior would be useful in developing relevant and efficient attentional focus. Through sufficient practice, learners could be helped to develop their attention focusing skills to the point that they became automatic. Visual and audio educational materials such as films, videotapes, and videodisc technology might be adapted or developed for these purposes. These forms of technology would expose the parent learners to visual and auditory cues they need to learn to

recognize in order to determine conditions in a situation that call for particular types of action. Helping parents realize the importance of being skilled observers of their children's behavior should be an integral part of the educational approaches developed to assist parents in more effective attention allocation. It is, therefore, recommended that educational approaches be developed to facilitate the development of attentional focus for problem solving in parenting and other ill-defined human interaction situations.

Another area with important implications for education is the area of knowledge content and structures relevant to a problem solving situation. Both the content and structure of knowledge were found to be factors influencing expert parental performance. The research evidence suggests that parental performance can be more effective when parents are knowledgeable about their own child and about child development and child rearing. Educational approaches need to be developed which directly teach parents child development knowledge and integrate that knowledge into what they have learned and continue to learn about their own specific child. This integration of domain and specific knowledge is likely to be facilitated by addressing the domain knowledge in relation to a variety of everyday parenting situations and contexts. Condition-action unit development is likely to be facilitated by educational approaches that help learners link child development concepts to cues and conditions revealed in children's behavior and to adult actions that meet goals desired for children in light of these cues and conditions.

Reif (1980) suggested that learners need to be helped to structure their knowledge hierarchically with specific knowledge embedded in more generally applicable knowledge for greater ease in remembering, retrieving, modifying, or flexibly applying in problem solving. Educational approaches need to be developed to help parents develop these more principle-driven strong schemas as Anderson (1984) described them. Parents might also be helped to locate or create more sources of knowledge to help them increase the amount and complexity of their knowledge structures. As parents are assisted in developing more sophisticated knowledge structures, they may also simultaneously improve their attentional focus skills since an increased knowledge base is likely to enhance their ability to more effectively note cues important to problem representation and solution. It is, therefore, recommended that educational approaches be developed to teach the knowledge base and develop knowledge structures relevant to identifying and solving various ill-defined problems in parenting and other areas involving human interaction.

Helping learners consciously consider the thought underlying their actions with their children is a third area in which results indicate implications for educational practice.

Educational approaches need to be developed which help parents become more consciously aware of their own assumptions and thought processes and patterns. For experts, the problem solving process included recognition and interpretation of cues in the situation based on available knowledge, setting goals and subgoals for the situation based on cue interpretation, and deriving plans for action related to appropriate parent role behavior for the situation. This entire problem solving process can be thought of in terms of production systems that involve conditon-action units (Anderson, 1985), structures which can be taught.

Recognition of conditions evokes actions, and the ability to recognize a condition is based to a large extent on pattern recognition. Practice in observation which includes systematic scanning of the task situation for appropriate cues is an instructional technique likely to enhance pattern recognition abilities as well as attentional focus abilities. Verbalization of goals and plans for action before making overt moves toward a solution is another instructional strategy that might be used to assist learners in becoming more aware of conditions and plans and relationships between them. Practicing these processes in simulated situations presented through the use of technology may be an effective means for developing these skills in educational programs. Such educational approaches would also provide learners with the opportunity to develop the metacognitive skills of planning, guiding, and monitoring their actions. It is, therefore, recommended that educational approaches be developed to teach cognitive processes, including pattern recognition and metacognitive skills, and knowledge structures underlying problem solving in parenting and other ill-defined human interaction situations.

For Further Research

This entire study was highly exploratory in relation to all of the variables examined, both those related to the mental processes and knowledge underlying effective parental action and those related to the methodology used. The study clearly has raised more questions than it has answered. Much further research is needed related to all aspects of the study in order to more fully address the research objectives. Recommendations for further research include the following:

1. Study problem solving behavior with other groups of subjects involved in solving other types of everyday, ill-defined human interaction problems. Both fathers and mothers need to be studied in problem solving situations with children of other age groups. Problem solving tasks and contexts need to be varied to assess the influence of the task and context on the type of problem solving behavior exhibited. Tasks selected should be as close as possible to real life ill-defined

problem situations in parenting. Parents should be studied who do not necessarily fall into the more extreme ends of the continuum of expertise in order to learn more about the stages individuals may go through in movement from novice to expert problem solving. Groups of caregivers other than parents might be studied in interaction with children in order to further assess differences in problem solving behaviors in interaction with children. Other groups of individuals involved in solving other types of everyday, ill-defined problems in human interaction need to be studied extensively since so little is known about how ill-defined, ill-structured problems are solved.

2. Further develop and test methodology for uncovering the thought processes and knowledge content and structures underlying expertise in problem solving. The research procedures of "thinking aloud" and stimulated recall were found to be effective in eliciting verbal data reflecting the thinking of the individuals engaged in problem solving. Because of the problems previously identified in determining the completeness and accuracy of this data, it is essential that these and other research approaches continue to be examined and perfected.

3. Investigate dispositions influencing performance in problem solving situations. It was initially an intent of this study to examine potential dispositions (e.g., motivations, interests, values, attentional biases, etc.) influencing performance in problem solving situations. The only data obtained related to individual dispositions were the statements made by the subjects concerning their goals or expectations for their child during the pre-task interview and the goals and subgoals parents had for the outcome of the problem solving task. These goals were analyzed on the basis of their child- versus parent-centered focus. Some metacognitive skills indicative of self-awareness were also evident in the experts' statements during problem solving. Much more research needs to be done to identify and assess dispositions and determine their impact on problem solving processes. Potentially important variables to investigate in this area include the cognitive developmental level of the subjects studied, the cognitive or learning style of the subjects, self-awareness, and other variables associated with personality differences. It would also be useful to examine the influence of subjects' general verbalization skills on the amount and content of their verbalizations in this type of study.

4. Develop and assess curricular designs and instructional approaches that facilitate development of the cognitive processes and knowledge content and structures found to be associated with expertise. Implications of the study results

for educational practice have been discussed and recommendations based on these implications have been made. Although much more research needs to be done to increase understanding of the cognitive processes and knowledge structures underlying effective parental action and effective action in other human interaction problem solving situations, it is imperative to begin to apply what is now known in these areas to curricular designs and instructional approaches. As curricular designs and approaches based on study results are designed and used in educational programs, research focused on both the process and the outcome of these educational approaches and programs needs to be done. These educational approaches and designs need to be tested with a variety of groups of subjects in order to learn more about how to effectively teach the recommended knowledge and skills to groups of varying age, and educational and experiential backgrounds.

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CHAPTER 4

CONCLUSIONS AND INSIGHTS REGARDING EXPERTISE IN SPECIFIC KNOWLEDGE DOMAINS AND IMPLICATIONS FOR RESEARCH AND EDUCATIONAL PRACTICE

Ruth G. Thomas

The two studies reported in Chapters 2 and 3 point to some general conclusions and insights regarding differences between experts and novices in specific knowledge domains. The findings support and elaborate previous findings regarding expertise in general and offer several clues for educational practice.

A broad generalization emanating from the two studies is that the essential difference between experts and novices is an intellectual one. Experts engage in far more intellectual activity when working with a problem situation than do novices. They have more mental resources with which to work. Since a primary function of education is the development of mental resources, it would follow that education has a key role to play in the development of expertise. But what kind of education will enhance expertise? This chapter summarizes the findings from the two studies which shed light on that question and offers some potential answers.

What are the essential intellectual attributes that differentiate experts and novices? Previous research has established that the knowledge base of experts and novices is different in amount, content and character. Experts not only have more knowledge than novices, but expert's knowledge contains more principles and functional relationships and is more interconnected, integrated and networked. The two studies provide more specific information about the nature of these differences in the knowledge base of experts and novices in relation to specific knowledge domains.

The studies also reveal how the knowledge base of experts and novices affects the way they operate in a problem solving situation. It would appear that differences in the nature of experts' and novices' knowledge is a primary factor underlying other differences. The processes critical to problem solving, i.e., focusing attention, generating knowledge, seeking information, using information sources, generating hypotheses, and action planning, influence effectiveness in resolving

problems. The two studies clearly indicate the influence of the amount and character of knowledge on these processes that form, organize and guide experts' actions. Table 1 and the subsequent discussion summarize the findings regarding differences in experts' and novices' knowledge and processes, and differences in the outcomes of their actions, revealed by the two studies.

Knowledge

Referring to the knowledge portion of Table 1, the studies indicate that specific knowledge domain experts possess larger amounts of both domain knowledge (concepts, principles, theories within the knowledge domain) and knowledge of specific systems or instances. The expert parents possessed much child development domain knowledge as evidenced in the child development concepts they referred to and much knowledge about their own child as evidenced by the typical behavior patterns they were able to describe. It would appear that the domain knowledge lent meaning and significance to the specific instance knowledge. The trouble shooting experts knew the specifics of the particular generator's subsystems and they knew the domain of electrical and mechanical systems.

Previous research has indicated that experts' knowledge is deeper and focused at a functional level whereas novices' knowledge is more shallow and focused at a descriptive, surface level (Rasmussen & Jensen, 1974). This difference was revealed in the ability of trouble shooting experts to make interpretations about the functioning or nonfunctioning of generator parts and the expert parents to indicate the functional purpose served by their child's behavior (e.g., exploring a book by chewing). Novices, on the other hand, could sometimes describe typical behavior patterns of their child but gave no indication of any function associated with the patterns.

Previous research findings that experts' knowledge is interconnected were confirmed and elaborated by the studies reported here. For example, the expert parents clearly could go back and forth between the knowledge they had about their own child and their domain knowledge of child development. The ability to connect various pieces of knowledge was apparent in the trouble shooting experts' initial assessment of the generator: "I can feel the fuel pump pumping so I know that I have voltage to my fuel pump. Therefore, that means my circuit board is good, am applying voltage, at this time I know that the fuse is good, and it gives me a pretty good indication that I do have battery power. At this time I don't know if it's enough because of the fact that the fuel pump draws less current than the starter does" (see p. 29).

The evidence provided by the studies that differences in the amounts and character of knowledge possessed by experts and by

Table 1

Comparison of Experts' and Novices' Knowledge, Processes, and Outcomes in a Specific Knowledge Domain Problem Solving Situation

	Experts	Novices
Knowledge		
Amount	extensive	minimal
Character	specific and general, functional level; integrated, interconnected	vague and general, descriptive level; discrete, unconnected
Processes		
Attention Focus	focus on relevant, high information yield cues	attend to many cues including irrelevant and low information yield cues
Knowledge Generation	generate relevant, additional knowledge, accurately interpret cues	generate little or no additional knowledge, do not interpret or misinterpret cues
Information Seeking	seek specific, relevant information	seek general information including much irrelevant information
Information Sources	memory, thinking, instruments	sensory data
Hypothesis Generation	generate relevant hypotheses	generate many irrelevant hypotheses
Action Planning	extensive, intellectually driven; directed toward relevant goals	minimal, sensory driven; not goal-directed, or directed toward irrelevant goals

(Table 1 continued on next page)

Consequences		
Information Obtained	specific, relevant; information sought is found	general, much is irrelevant; not all information sought is found
Effort	focused; high yield for amount of effort	unfocused; low yield for amount of effort
Outcome	effective, appropriate action	no action or inappropriate or ineffective action

novices can be revealed either by objective testing or by analyzing discourse is useful for researchers and for those concerned with assessing expertise.

Processes

Turning to the processes portion of Table 1, the intellectual differences between experts and novices was reflected in these two studies by the way the experts and novices allocated the precious and scarce resource of attention. Experts directed their attention focus by their intellect; novices guided their attention focus by their senses. As a result of experts' greater intellectual activity and resources, their attention was focused almost entirely on relevant cues. Further, the cues they attended to had a high information yield. Thus, experts were able to reduce and confine their attention to smaller and smaller portions of the generator, to fewer and fewer subsystems. Lacking the intellectual resources of experts, novices used a shotgun approach, focusing their attention randomly on more cues, and used up attentional resources on irrelevant or dead end cues which reduced the availability of attention for profitable cues. Consequently, novices could not so quickly reduce the area over which to allocate their attentional resources. In the parent-infant study, experts focused attention on their child, a focus which yielded much useful information about the child's state and implications for parental response. The novices focused attention on the toys which provided little information about the child's state and few clues about appropriate parental response.

Moving to the knowledge generation portion of Table 1, experts' interconnected knowledge enabled them to generate more knowledge from a few critical cues they detected in the

situation. They also possessed tools (for example, formulas) that enabled them to generate additional knowledge and they applied the tools appropriately and accurately. A single cue did indeed appear to activate "chunks" of stored knowledge for the experts as indicated in the quote from a trouble shooting expert's protocol (see p. 29). In the way that an expert card player knows the hands of all the opponents after the cues provided in the first and second round of play, and can thus "zero in on" the weaknesses in the opponents' hands, so an expert trouble shooter knows which subsystem to zero in on after finding a few strategic cues.

Regarding information seeking, the specificity of experts' knowledge appeared to influence their search for new information. In the trouble shooting study, experts sought more specific information whereas novices sought more general information. These findings suggest that the type of information sought in a problem solving situation appears to be related to the type of information already possessed. It has been well established in psychological literature that perception and what is learned is influenced by what one already knows in a way that preserves cognitive consistency. The trouble shooting study suggests that this consistency principle holds true not only for knowledge content but also for its nature and character.

The consistency principle also seemed to apply to the use of information sources. Experts in the trouble shooting study relied on technical evaluation as a source of information (e.g. testing with a gauge, looking up a reading on a chart, running a figure through a mathematical formula, performing a logical analysis based on knowledge of functional relationships to deduce existing conditions), whereas novices relied on sensory-dependent exploration (looked for surface visual, auditory, olfactory and kinesthetic cues) to provide information. Consequently, cues accessible to sense perception could be apprehended by the novices (as in the fuel pump problem) but cues requiring instruments or deduction to detect (as in the open wire problem) were inaccessible to them. Experts possessed the knowledge and skill required to be able to use more technical sources of information; novices did not. Novices could not use information sources they did not have the tools to access. In the parent-infant study, experts had keen skills for observing their children as a source of information. Novices used child observation far less than the experts and were not skilled observers when and if they did observe their child.

The sensory-dependent information acquisition of novices also influenced their hypothesis formation because it limited the information available to them to sensory data. Novices generated more hypotheses than the experts in the trouble shooting study - but more than one-third of the novices' hypotheses were irrelevant. Parents generated hypotheses about their child's

states (she's bored, chewing feels good). Expert parent's deeper knowledge of child development principles and their own child's behavior patterns from a functional standpoint enabled them to generate accurate hypotheses whereas novices either ignored their child's states or generated highly improbable hypotheses.

The intellectually driven character of experts' action planning in the two studies is further evidence that the key differences between experts and novices are intellectual ones. In both studies, the experts had a plan about where they were going and what they were going to do and they knew why. Experts' plans were focused and specific. Novices, on the other hand, had no plans or had vague and general plans, seeming to cast around for actions with no systematic or structured ideas in mind. This unplanned, aimless meandering through a problem space is captured in the novice's verbal expression of intended action in the technical trouble shooting study: "I'm just gonna kind of look around, take a look at it for a minute" (p. 29). Another problem related to planning that limited novices was the "stuck" plan. An example of this was the "one plan novice" that could not flexibly adjust her plan to take into account information that became available during the course of the infant engagement activity. Her being stuck in one, inflexible plan is documented in the action plan portion of Figure 6 in Chapter 3 (in the @@@@@@@ bordered rectangle) which indicates that her plan was to get her child to do different things with cups and observe his reactions. She did this despite obvious cues from the child that this plan did not fit the child's desires, interests or needs. It appeared that either she did not apprehend the cues, or noted them but could not interpret them. An inappropriate plan was a third action planning problem demonstrated by this novice. When she did at last change her plan (show a new toy), it was not responsive to the child's cues.

Experts appeared to use the information they obtained from cues in a situation and from their own store of knowledge to determine and assess prevailing conditions and then base their action plan accordingly, again drawing on their store of knowledge about what plans work under such conditions. A helpful discussion of plans and plan repertoires that describes the mental resources that support action plans is available in Schank and Abelson (1977).

The experts' evidence of action planning confirms and elaborates previous findings that experts skillfully monitor and control their own actions. This ability of experts, referred to in Chapter 1, involves highly developed, largely automatic mental processing and control routines. The self reflection of the mother who commented about changes in her own reactions to her child ("I would have taken it personally when I was younger") was an example of the monitoring function. It enables experts to be conscious of and keep track of where they are in a process.

Such monitoring and control processes, called metacognition in the cognitive science literature, appeared to be absent from novices' protocols.

Consequences

A significant consequence of the differences in the knowledge of experts and novices and their processes was that experts obtained more high quality information than did the novices. Information obtained by experts was relevant to the problem. Novices obtained as much or more irrelevant as relevant information. For example, in the case of the parent-infant study, novices appeared to obtain information about the toys to a greater extent than they obtained information about their child. The toys caught their attention and they lacked control processes to more strategically direct their attention.

Novices expended more effort for less results. Seeking information they didn't find, exerting effort to obtain irrelevant information, focusing on cues that yielded little information, misinterpreting cues they did apprehend, and generating a large number of hypotheses, one-third of which were irrelevant, represented low yield effort expenditure on the part of novices. Experts, on the other hand, pursued cues in a strategic manner that allowed them to reduce the number of further cues to be investigated. Experts had subsystem concepts which helped them to exclude whole portions of the problem space from further consideration and exploration. Novices pursued cues in a seeming random fashion which did not reduce the size of the problem space they continued to explore.

The outcomes for novices and experts were different in most instances. In the trouble shooting study, the experts were able to discover the system fault. While the novices were able to solve the fuel pump problem in which the critical cues were more accessible to sensory detection, clear differences in outcomes between the novices and experts were apparent in the open wire problem. In the parent-infant study, while both groups were successful in engaging their infant's interest in the toys, repeated negative reactions by the infants to parent's responses were evident in the novices' protocols but not in the expert protocols.

Summary

The differences between novices and experts, in the processes identified in Table 1 indicate that experts are better <u>selectors</u> than novices. Experts are better at selecting where to focus their attention. They select better information sources, better hypotheses and better action plans. Just as the expert farmer <u>selects</u> a hybrid corn variety that fits the climate, soil and terrain conditions for a high yield, so the expert problem

solver selects information from the problem space and his or her own knowledge store to fit the patterns in the problem for a high information yield. Because experts were good selectors of information, they had a more informed basis for selecting hypotheses and action plans.

The primary underlying factors in this superior selection skill of experts appear to be the content and organization of their knowledge which provides them not only with patterns against which to match perceived information, but that is also accessible in relation to the problem at hand.

It appears that expertise might be likened to a pair of glasses or lenses that enables one to see selectively, causing irrelevant cues to fade to the background and relevant cues to stand out in almost a perceptual figure-ground relationship. To experts, figure is clearly differentiated from ground. Novices can't distinguish figure from ground.

Differences in the nature of problems and their requirements are also evident in the studies. Hypothesis formation was prominent in the technical trouble shooting study and guided information seeking. Goal selection was a factor in the parent-infant study which also involved some hypothesis formation in the parents' hunches about why their child was acting in a certain way. In this study both goal selection and hypothesis formation guided action planning. It would seem that most problem solving involves both hypothesis formation and goal selection. In the two studies the linkage between knowledge and hypotheses or knowledge and goals was evident for experts and lacking for novices who tended to generate irrelevant hypotheses and unrealistic goals. Role selection was also evident in the parent-infant study and would seem to be closely linked to goal selection. It is anticipated that role choice would be an important dimension in some problems, especially those involving human interaction.

Implications for Further Research and Educational Practice

Prerequisites for specific domain expertise indicated by the studies presented here would appear to be extensive, integrated knowledge of the domain and of specific cases and a repertoire of action plans linked to conditions. Such prerequisites appear to enable perception of relevant cues, focused attention on such cues and formulation of appropriate and effective plans for action. Education that provides learners with these prerequisites is likely to enhance their expertise.

Unfortunately, while we know considerably more now than was known ten or even five years ago regarding the attributes of and key factors in expertise in general and are learning through studies such as the two presented here what the specific

attributes and key factors are in expertise in a particular knowledge domain, little research has focused on the developmental processes involved in becoming an expert. Most research has studied people who have already attained expertise or compared experts and novices at one point in time. Sylvia Scribner who has conducted research on learning that takes place on the job (1984) is now investigating such learning over time. Studies that contribute insight as to the role of formal education and that of experience in developing expertise would also be helpful in better understanding the degree of interchangability and the trade offs between the two. Some studies have yielded promising results for instruction involving computer assisted simulation as a promising alternative to job experience in cutting learning time (Lesgold, et al, 1988).

The challenges for vocational education research are to continue to study the nature of expertise in specific knowledge domains associated with vocational education so that a solid foundation of understanding can guide instructional design, and to develop and test various instructional designs for their impact on learners' mental resources relevant to expertise in specific knowledge domains.

Although there is still much to learn and understand about how expertise develops as a basis for instructional design, some potentially useful clues are evident in the research findings from these two studies. First, attention should be paid in designing instruction to the way knowledge is structured for teaching. For example, it would seem that technical troubleshooting programs should provide learners early on with a mental picture of the technical system and its subsystems. Such an approach is likely to provide the "pegs" on which to hang and arrange the detailed information about each subsystem and is likely to facilitate chunking as well as provide a mental model. Such an approach is also suggested by Shank and Abelson (1977). In the parent-infant interaction domain, alternative parent roles would seem to provide a similar "system level" picture to which toys or other situational factors and children's states and behavior could be linked. Such an approach would provide a highly generalizable skeletal concept on which to hang the details of many different kinds of technical equipment or situations with human beings of different ages and relationships. Making the structure of the knowledge being taught explicit and introducing it early in the learning sequence (just as the frame for a house is a clear outline of the house and is done early in the building process) would seem to be two key factors. Further, introducing a set of subsystems and then providing more depth on each would seem to set this conceptual framework more successfully than introducing each subsystem separately and providing all of the detail about one before moving on to the next subsystem. Introducing a set of concepts minus detail in the beginning also would seem to set the stage

for understanding relationships between the concepts. Finally, as broad, theoretical concepts are taught, specific examples should be part of the instruction to facilitate the embedding of domain knowledge in specific instance knowledge. The specific examples instruction is likely to be more successful if learners experience the example situations or problems as directly as possible and are assisted in linking domain knowledge to knowledge of specific instances by making such linkages explicit in the teaching process.

The studies suggest why simply having experience may not necessarily turn the novice into an expert and why it is important in the instructional process to make the links between cues, conditions, goals, roles, hypotheses, and action plans explicit. The sensory dependency of novices appears to interfere with development of expertise. The inability of novices to apprehend relevant, critical cues that cannot be detected through sensory means alone or at all limits novices' ability to form critical cue patterns which in turn limits their ability to apprehend critical cues. The expert's ability to apprehend critical cues, on the other hand, and to note unique or unusual cues is likely to expand the expert's memory store of cue patterns, elaborate old patterns, and make the expert even more expert. This circularity is akin to the adage, "those that have, get."

Regarding what to teach, the findings in the two studies suggest the importance of drawing novices' attention to critical cues in the learning process. A task for education is to make novices aware of how they focus their attention and educate them to allocate their attention and effort to high yield cues. Teaching learners ways to perceive critical cues that are not detectable by simple sensory exploration is also necessary. As an infant is limited to sensory exploration as a method of information acquisition in the absence of the conceptual store that future experiences will provide, so is a novice limited in exploring an unfamiliar problem space. Similarly, when science was limited to exploration with the naked eye, it developed concepts and hypotheses based on the limited and often irrelevant information which could be obtained by that sense. The practice of blood letting of sick people was stopped, for example, once more critical cues (the presence of microorganisms) could be apprehended with the microscope. Education for expertise must provide learners with the tools to seek information from relevant, high yield information sources.

Learners should be exposed in the learning process to problems that require functional level understanding. Such problems would also be useful for assessment of learning, particularly at the end of an educational unit or program. Such problems will be more difficult for students than problems which demand only understanding of surface characteristics of

phenomena and sensory detection of critical cues. This aspect of difficulty should be considered in sequencing instruction.

Instructional techniques that meet the demands outlined above need to be developed. Simulations would appear to provide a rich experience for learners in the processes outlined in Table 1 and opportunities to increase the links between aspects of their knowledge base. Computer assisted simulations would seem to have particularly rich potential for providing needed guidance and explication of cues, information sources, and links between hypotheses, goals, roles and action plans and knowledge elements.

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